EXCLUSIVE: A 20-year solar eclipse planner p. 49

SEPTEMBER 2021

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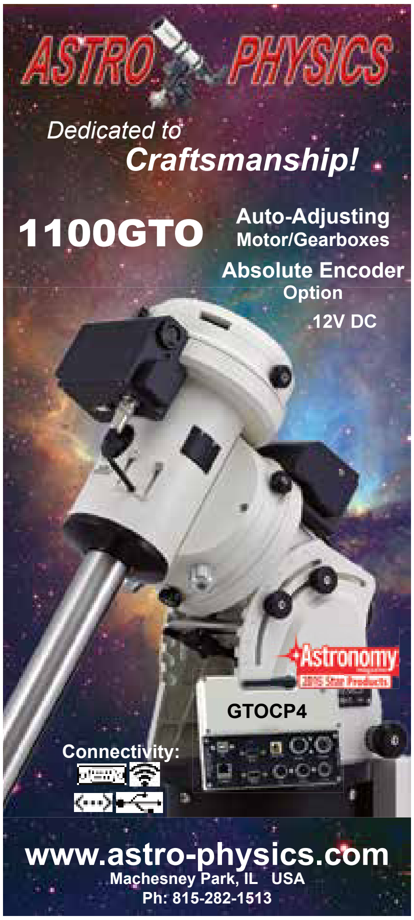
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CFHT / COELUM - J.-C. CUILLANDRE & G. ANSELMI

ON THE COVER

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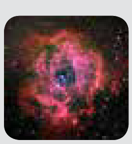
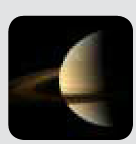


Picture of the Day
Gorgeous photos from our readers.

My Science Shop
Perfect gifts for your favorite science geeks.



News
The latest updates from the science and the hobby.

Ask Astro Archives
Answers to all your cosmic questions.

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FROM THE EDITOR

Go to *Infinity & Beyond*

Astronomy's new video series stars outreach enthusiast Abigail Bollenbach.

Do you know about *Astronomy*'s exciting new video series? It's called *Infinity & Beyond*, and explores a huge range of astronomical topics and exactly what we know about them in this golden age of cosmic research.

Commenced in mid-2020, our series has thus far produced 20 really informative episodes that you can use to keep up with the latest scientific findings. The series also enables you to enjoy your hobby of observing the sky, making the most of the time you have under the stars.

Infinity & Beyond is hosted by a young, knowledgeable, and very enthusiastic astronomy outreach expert, Abigail Bollenbach. An Oklahoma native and a college student looking toward an astronomical career, she is a winner of the Astronomical League Horkheimer/Smith Youth Award. Abby is also an Explore Alliance Ambassador for Explore Scientific, and has been a speaker at a variety of star parties. Her intellect and engaging personality shine through in each episode of *Infinity & Beyond*.

Thus far, the video series has taken on a wide swath of astro subjects. Abby has spoken about astrophysical subjects like the Big Bang, the Cosmic Microwave Background Radiation, the nature of dark matter, and our understanding of quasars. She has tackled planetary science topics such as our exploration of Pluto, the cottage industry of exoplanet discoveries, the Perseverance rover's findings on Mars, and why Venus turned itself inside-out. Abby has also explored some intriguing topics we all like to ponder, such as how the science portrayed in *Star Trek* and in *Star Wars* relates to reality.

I encourage you to check out these informative and entertaining videos. You can find *Infinity & Beyond* on *Astronomy*'s website under the Videos tab, or on our YouTube page. Enjoy!

Yours truly,

David J. Eicher
Editor

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Edgar Mitchell stands on the Moon during the Apollo 14 mission. NASA

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Remembering Apollo 14

I wanted to thank you for the wonderful Apollo 14 retrospective articles in your May 2021 issue. I had the distinct honor of not only meeting Dr. Edgar Mitchell many times but teaching his son, Adam, in my astronomy class in Boca Raton, Florida. Dr. Mitchell was very gracious in helping my class during our annual Kennedy Space Center field trip. We were able to visit and get a group picture in front of the Apollo 14 command module, *Kitty Hawk*. Your article brought back some great memories!

—Lachlan Mackay, Boca Raton, FL

What in the world ...

So, what is a *blanet* ("The galaxy's marvelous rogues and misfits," April 2021)? Sorry, I just had to ask.

—David Gunn, Portland, OR

Senior Associate Editor Alison Klesman responds: *Normally, planets form from leftover material (gas and dust) in the disk surrounding young, newly formed star. However, researchers have recently theorized that planets could form not only from material around a star, but also from the same kind of material swirling around — and ultimately into — a black hole. So, a blanet is a hypothetical starless planet thought to form inside the accretion disk around a supermassive black hole in a galaxy's center.*

No blanets have yet been found, but if and when they are, there is much these objects could teach us about the strange conditions surrounding the universe's most massive black holes.

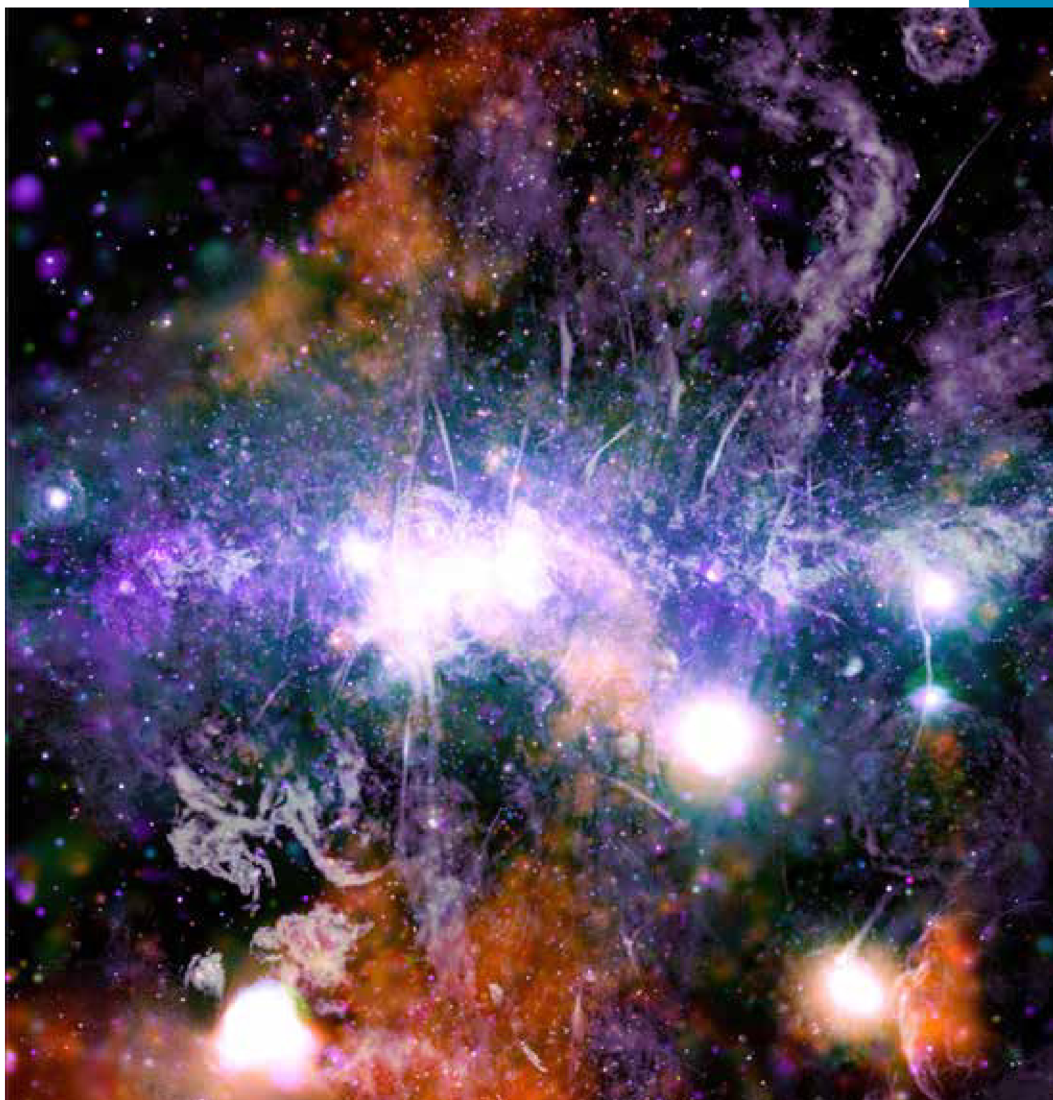
Correction

Our readers pointed out a mistake in the caption for the second question of the May 2021 Ask Astro (page 61), which incorrectly stated that Venus is two times farther from Earth than Mars. At their average distances from Earth, Mars is 49 million miles (78 million kilometers) and Venus is 26 million miles (42 million km), putting Mars at a greater distance.

SNAPSHOT

A CHAOTIC COSMIC TAPESTRY

Chandra and MeerKAT capture a magnetic masterwork.



This vivid scene resembles a Jackson Pollock painting — an abstract expression of line and color splashed across the center of our Milky Way Galaxy. But another analogy for the physics at work might be a tapestry woven by magnetic threads.

The broad regions of color (orange, green, and purple) represent X-ray emission with different levels of energy observed by NASA's Chandra X-ray Observatory. The narrow filaments in gray are radio observations from the MeerKAT array in South Africa.

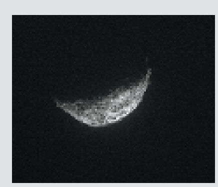
Many of these complex structures — some of which appear both in X-rays and radio waves — are produced by plumes of superheated gas and the twisted strands of magnetic fields near the center of our galaxy. Where these plumes collide, their magnetic threads are constantly snapping and reconnecting. This releases energy that generates radiation, in a process similar to activity on the Sun that generates outbursts and space weather.

— MARK ZASTROW

» HOT BYTES

HIGH-ENERGY HAUL
The Large High Altitude Air Shower Observatory in China's Sichuan province has detected the most energetic photon ever seen. The photon slammed into Earth's atmosphere with an energy of 1.4 quadrillion electron volts (1.4 PeV).

FARSIDE VIEW
A proposal to use rovers to build a radio telescope inside a crater on the Moon's farside won a $500,000 NASA grant to study its feasibility. The 0.6-mile-wide (1 km) wire-mesh dish would be shielded from human-made interference.

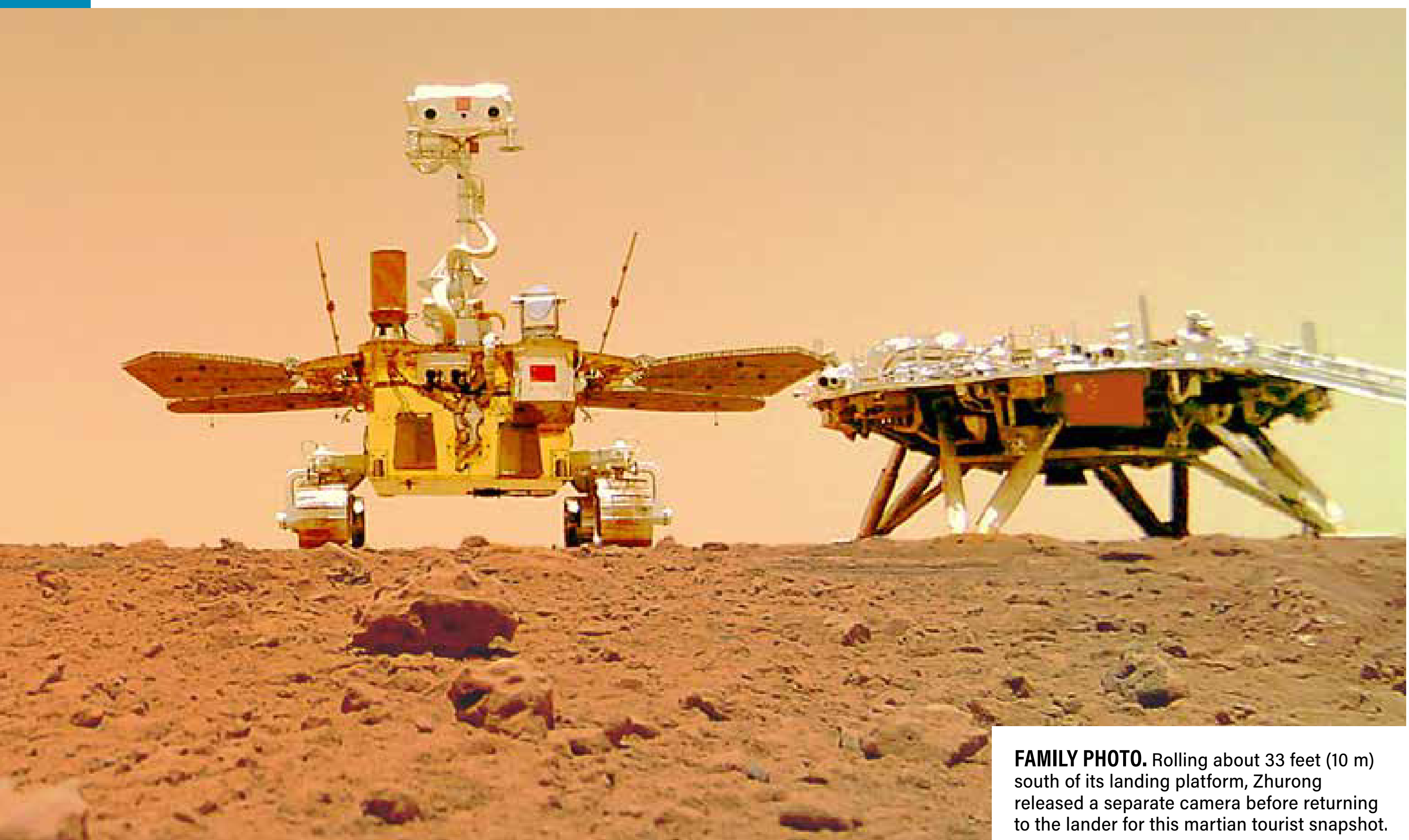


FAREWELL, BENNU
NASA's OSIRIS-REx mission departed asteroid 101955 Bennu on May 10 to begin its return journey to Earth. In October 2020, the craft collected at least 0.9 pound (400 g) of samples from Bennu's surface.

X-RAY: NASA/CXC/UMASS/Q.D. WANG; RADIO: NRF/SARAO/MEERKAT. BOTTOM FROM LEFT: INSTITUTE OF HIGH ENERGY PHYSICS; VLADIMIR VUSTYANSKY; NASA/GODDARD/UNIVERSITY OF ARIZONA

CHINA'S FIRST MARS ROVER TOUCHES DOWN

Zhurong's successful start on its martian trek makes history.



FAMILY PHOTO. Rolling about 33 feet (10 m) south of its landing platform, Zhurong released a separate camera before returning to the lander for this martian tourist snapshot.
CHINA NATIONAL SPACE ADMINISTRATION

» At 7:18 P.M. EST on May 14, a six-wheeled rover the size of a small car plunged into Mars' thin atmosphere, braking with a series of parachutes and retro-rockets. In a picture-perfect landing, Zhurong touched down on the lava plains of Utopia Planitia and stretched out its solar panels, making China the second country to successfully land and operate a rover on Mars.

As the news reached the Beijing Aerospace Control Center, where it was the morning of May 15, bleary-eyed engineers erupted in thunderous applause. With its successful touchdown, Zhurong, named for an ancient Chinese god of fire, has now vaulted China into the hallowed ranks of nations with a multiplanetary presence.

MAKING HISTORY

Zhurong's journey began in July 2020, when it launched aboard the Mars-bound Tianwen-1 spacecraft. The mission reached the Red Planet on Feb. 10, 2021, about a week before NASA's Perseverance rover arrived. Unlike NASA's craft, which deposited the rover immediately on the surface upon its arrival Feb. 18, the Tianwen-1 orbiter then circled Mars for a few months, scouting out the best landing site for the rover.

Previously, the U.S. and the Soviet Union had been the only two countries to land spacecraft softly on Mars. The USSR's Mars 3 mission achieved the first soft landing in 1971, but its rover only transmitted for 20 seconds, sending a partial image to its orbiter before ceasing communication. Despite numerous other attempts, the USSR failed to beat the U.S. to successfully landing and operating a robotic

martian mission; NASA's Viking 1 took that honor in 1975.

Now, nearly 50 years later, China is making history by becoming just the second country to properly land and operate a mission on Mars, capping the nation's decade-long leap to the forefront of space exploration.

"You were brave enough for the challenge, pursued excellence and placed our country in the advanced ranks of planetary exploration," said Chinese leader Xi Jinping, according to Reuters. "Your outstanding achievement will forever be etched in the memories of the motherland and the people."

SCIENTIFIC OPPORTUNITY

Beyond its technical success, Zhurong has also caught the attention of researchers worldwide for one simple reason: its landing site. Zhurong is exploring Utopia Planitia — an area of Mars that planetary scientists have wanted to revisit ever since NASA's Viking 2 lander operated for several years there in the late 1970s.

Utopia Planitia is the largest known impact basin on Mars — or anywhere else in our solar system. The terrain is full of interesting geological features. And below its surface lies a frozen lake that holds about as much water as Lake Superior, Earth's largest freshwater lake by surface area.

Of particular interest in Zhurong's vicinity is a mud volcano, a landform no other martian rover has explored. Researchers believe mud volcanoes form when a mixture of water and soil erupts to the surface. On Earth, mud volcanoes are inhabited by bacteria that produce methane.

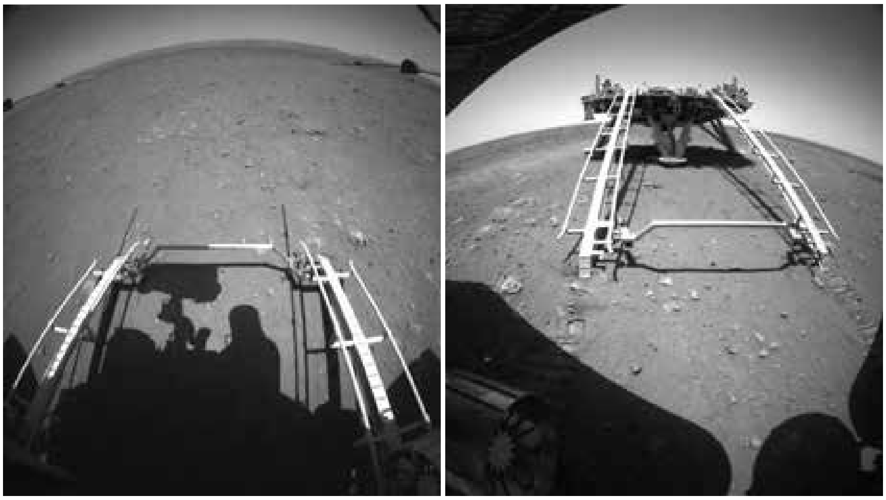
All of that makes Utopia Planitia a prime place to explore. Like NASA's Perseverance rover, Zhurong will also stash Mars soil samples that China eventually hopes to retrieve.

The road ahead for Zhurong won't be easy. Officials at the China National Space Administration (CNSA) say the rover landed in an area riddled with rocks and more craters than expected. However, engineers think the rover is up to the challenge.

CNSA says it expects the rover's mission to last just 90 days. But the space agency said the same thing when its Yutu-2 lunar rover landed on the Moon in 2019 — yet that rover is still active today. And NASA's Mars Opportunity rover's initial 90-day mission was ultimately extended more than 14 years, giving it time to trek across some 28 miles (45 kilometers) of terrain.

Even if Zhurong doesn't live up to the lengthy legacies of past rovers, it has already succeeded where so many Mars spacecraft have failed in the past.

—ERIC BETZ



WHEELS DOWN. On May 22, the Chinese space agency's Zhurong Mars rover left its landing platform and safely drove onto the Red Planet's surface. CHINA NATIONAL SPACE ADMINISTRATION

QUICK TAKES

SPLISH SPLASH

Nearly six months after hitching a ride to the International Space Station (ISS) aboard a SpaceX Falcon 9 rocket, NASA's first commercial crew — carried by a SpaceX Crew Dragon capsule — safely splashed into the Gulf of Mexico near the coast of Panama City, Florida, on May 2.

COSMIC HUM

Voyager 1, which launched in 1977 and is now near the edge of the solar system, detected a faint but persistent murmur coming from the relatively empty space between stars. According to new research, the hum is from low-level, long-lasting vibrations in interstellar plasma.

FLOATING FILM

Russia's Roscosmos space agency recently announced plans to send a director and actress to the ISS to shoot a movie tentatively titled *Challenge*. The expedition is expected to launch from Baikonur Cosmodrome aboard a Soyuz spacecraft in October.

NASA'S NEW ADMIN

Vice President Kamala Harris swore in Bill Nelson, former U.S. senator from Florida, as NASA's 14th administrator on May 3. In the Senate, Nelson spearheaded the creation of the Space Launch System, the rocket that will fly Artemis missions to the Moon. In 1986, as a congressman, he flew aboard the space shuttle *Columbia*.

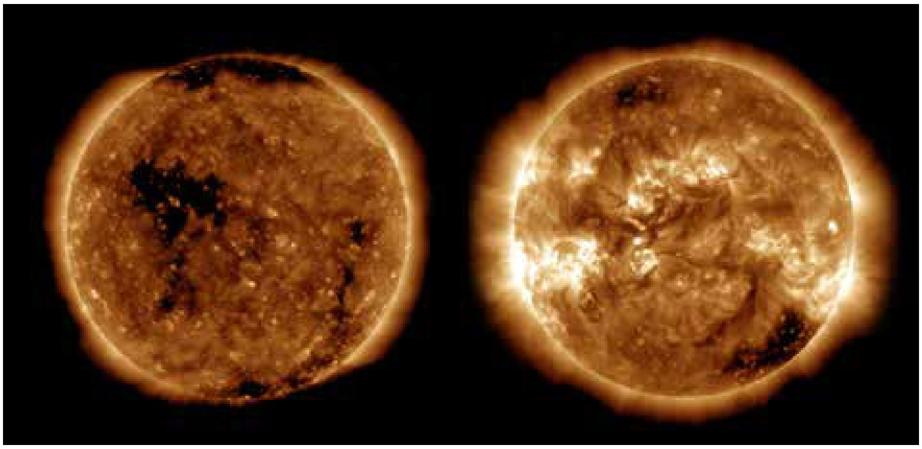
EXPLOSIVE ARMS

With the help of the Hubble Space Telescope, astronomers have pinned down the origins of five brief but powerful blasts called fast radio bursts. The team traced the enigmatic explosions to the spiral arms of five distant galaxies and hopes identifying their origins will shed light on what causes them.

SURVIVABLE IMPACTS?

Tardigrades are tiny creatures that can temporarily survive extreme conditions, including the vacuum of space. But new research shows they can't survive impacting sand at speeds higher than 2,000 mph (3,200 km/h). This could place limits on the theory of panspermia, which suggests life arrived on Earth in a meteorite impact. —JAKE PARKS

Artemis delays may expose astronauts to hazardous space weather



AT EXTREMES. Our Sun undergoes an 11-year cycle during which its activity peaks (right, from April 2014) and wanes (left, from October 2019). NASA'S SOLAR DYNAMICS OBSERVATORY/JOY NG

NASA's Artemis program aims to land astronauts on the Moon by 2024. But spaceflight delays are common, so it was no surprise when, in a February interview with *Ars Technica,* NASA acting administrator Steve Jurczyk said 2024 may no longer be a realistic goal.

According to a paper published May 20 in *Solar Physics,* the delay might have a potentially dangerous consequence: increasing the risk that astronauts and spacecraft will be exposed to extreme space weather.

Space weather results from activity on the Sun and sends energetic particles racing through the solar system. The largest and most extreme events can damage satellites or spacecraft and disrupt power grids on Earth. This radiation also poses serious health risks to astronauts above Earth's protective atmosphere, and the most extreme events could sicken or even kill astronauts if they aren't protected by shielding.

The Sun has a regular 11-year cycle driven by changes brought on when its magnetic field flips. It entered cycle 25 in December 2019. Each cycle has a minimum and a maximum of activity, and astronomers have long known that mild to moderate outbursts and space weather are more likely to occur during a maximum, as well as during solar cycles that yield more sunspots.

In their new paper, the authors analyzed 150 years of records and found that the most extreme — and rarest — space weather events follow this same pattern. Their analysis also showed that extreme space weather events occur earlier in even-numbered solar cycles and later in odd-numbered solar cycles. They think this behavior could be related to the overall polarity of the Sun's magnetic field during each subsequent cycle — i.e., which way is north and which way is south. That polarity flips during each solar maximum, so it starts out pointing different ways during even- and odd-numbered cycles, which begin at solar minimum.

All this means that if Artemis is pushed back into the latter half of the 2020s — during odd-numbered solar cycle 25 — the risk from extreme space weather will increase. While extreme storms are less likely between now and 2026, the researchers say, the interval between 2026 and 2030 will carry a higher likelihood of big events that mission planners may have to consider.

In this case, forewarned is definitely forearmed. —ALISON KLESMAN

ESA/HUBBLE, R. SAHAI

HUBBLE HIGHLIGHTS A TWO-FACED NEBULA

The word *nebula* is itself a nebulous term: It means any cloud of dust and gas in space. So astronomers have broken down the category into several types, including emission nebulae such as NGC 2313, seen here in a recent Hubble Space Telescope snapshot. As their name suggests, emission nebulae emit their own light, releasing energy that is absorbed from a nearby star — in this case, V565 at the center of the image. NGC 2313 was once further classified with the now-defunct term *cometary nebula,* thanks to its lopsided appearance, which makes it look a bit like a comet with a tail. This occurs because a dense region of dust obscures the bright gas on the right side of the image, dimming and reddening half the nebula's splendor. —A.K.

Nickel vapor found in faraway comets

» Comets are metal — but not in a mosh pit, headbanger sort of way. Rather, two teams of European researchers have found traces of nickel and iron gas in cometary atmospheres.

While heavy metals like these are common throughout the galaxy in solid form, astronomers usually find them as a gas only in very hot locales, such as the atmospheres of exoplanets close to their host stars. But a team from Belgium using the European Southern Observatory's Very Large Telescope (VLT) found that nickel and iron vapor are ubiquitous in comets throughout the solar system — even those far from the Sun.

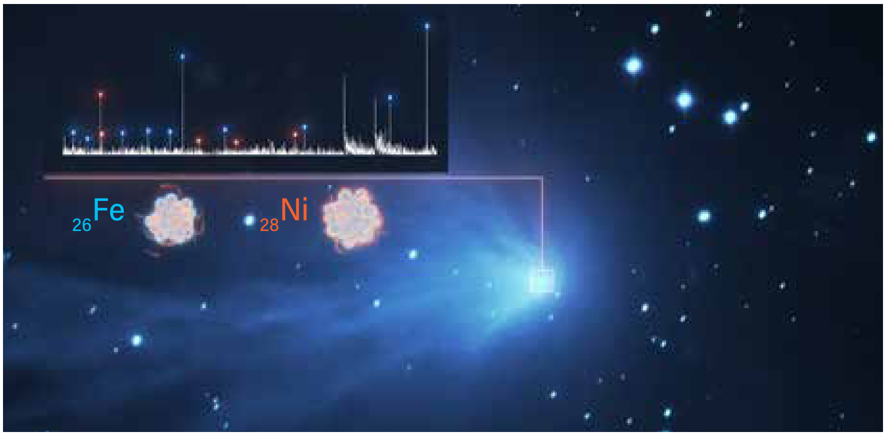
The results aren't limited to comets in our solar system, either. A Polish team that used the VLT to study the interstellar comet 2I/Borisov as it flew past the Sun in 2020 also found nickel vapor in its atmosphere. Both papers were published in *Science* May 19.

"We were the most surprised and excited by the fact that the gaseous nickel is present in such a cold place at all," Piotr Guzik, lead author of the paper on Borisov, tells *Astronomy*. He and his coauthor, Michał Drahus, both of Jagiellonian University in Poland, think the nickel vapor was not released directly from the comet's cold nucleus. Instead, they believe it was released when complex molecules containing nickel sublimated, turning directly from a solid to a gas, at lower temperatures than are required for nickel itself to vaporize.

But even more significant is that the two papers demonstrate "that comets similar to the ones that we know from our solar system also form around other stars," Guzik says.

Finding nickel traces in comets from two different solar systems raises the possibility that both stars — Borisov's home star and our own Sun — formed in the same nebula. "The chemistry of 2I/Borisov doesn't exclude the possibility," says Guzik.

But, he says, to make a stronger connection, researchers would have to retrace Borisov's orbit. This is difficult because the gas the comet spewed as it passed through the solar system altered its trajectory. Borisov's origins may remain forever shrouded in mystery. —HAILEY ROSE MCLAUGHLIN



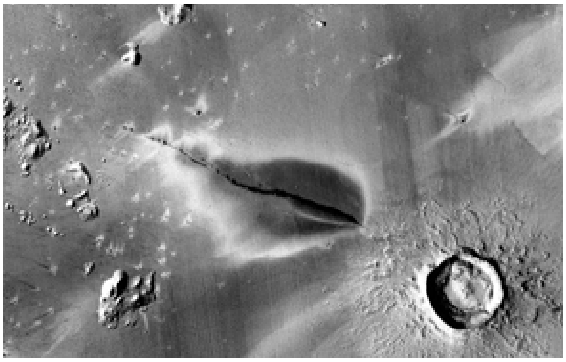
HEAVY METAL. The spectra of iron (Fe) and nickel (Ni) are superimposed onto this image of comet C/2016 R2 (PANSTARRS). ESO/L. CALÇADA, SPECULOOS TEAM/E. JEHIN, MANFROID ET AL.

30 million

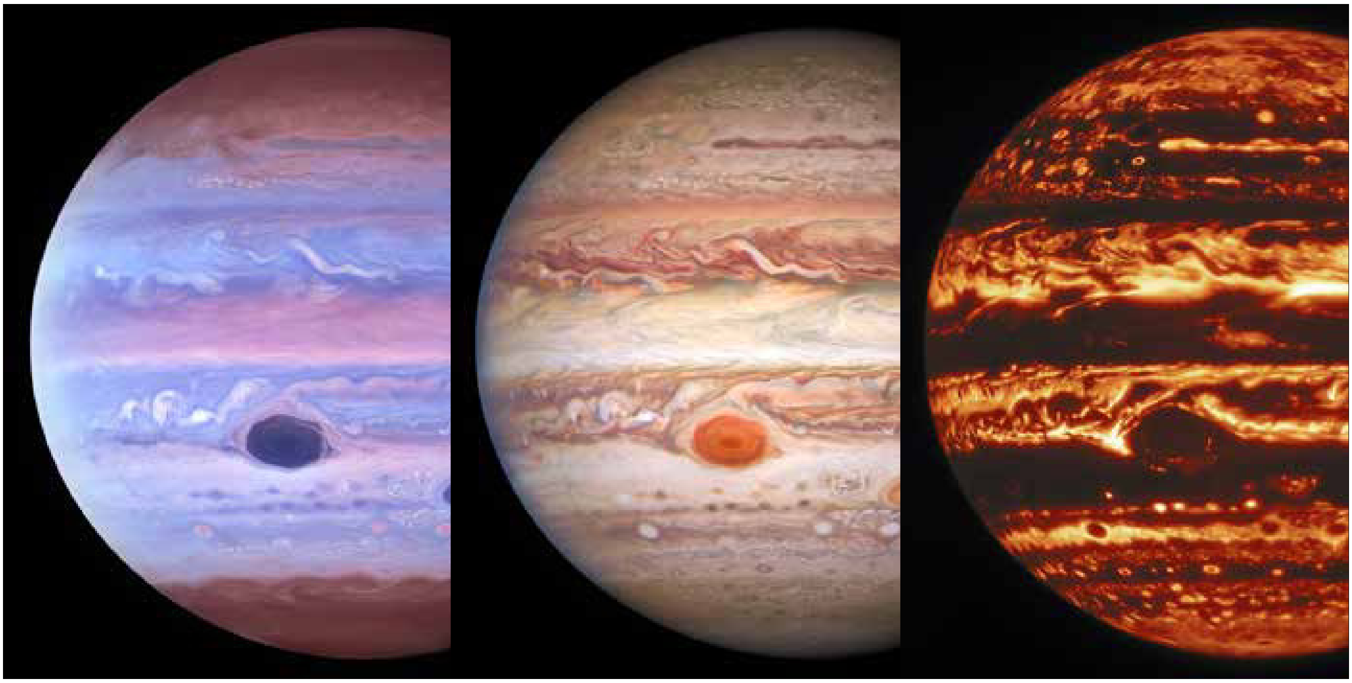
The number of galaxies the Dark Energy Survey will observe with a custom-built camera at the Cerro Tololo Inter-American Observatory in its quest to construct a 3D map of the universe.

Recent volcanism on Mars

Most volcanic eruptions on Mars occurred between 3 billion and 4 billion years ago, with some evidence suggesting the Red Planet's youngest volcanoes were still active as recently as 3 million years ago. New data from satellites orbiting Mars indicate volcanoes may have continued to rage on the planet until a mere 50,000 years ago. Researchers spotted what appear to be recent volcanic deposits around a young tectonic fissure known as Cerberus Fossae. This system lies within Elysium Planitia, the second largest volcanic region on Mars. NASA's InSight lander also detected two powerful marsquakes originating from Cerberus Fossae earlier this year. Scientists believe that activity could point to magma still flowing beneath the surface of the Red Planet. —CAITLYN BUONGIORNO



NASA/JPL/MSSS/THE MURRAY LAB



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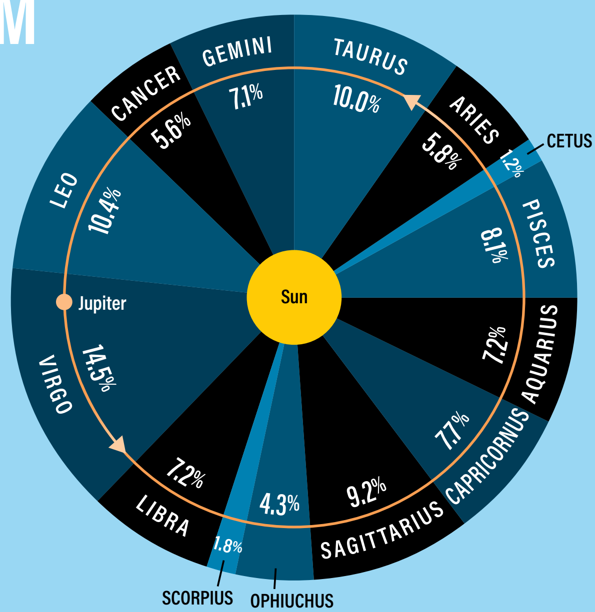
Jove, the colorful giant

There's no shortage of stunning Jupiter shots out there. But this striking set of images showcases just how different the gas giant appears when viewed in different wavelengths of light. Notice that Jupiter's most recognizable feature — the Great Red Spot — is almost entirely invisible in the infrared shot (right) taken by the Gemini North telescope in Hawaii. Meanwhile, the famous raging storm, along with nearby Oval BA (or Red Spot Jr.), is obvious in the visible (middle) and ultraviolet (left) images, both obtained using the Hubble Space Telescope. All three views were simultaneously captured at 15h41m UT on Jan. 11, 2017. – J.P.

JUPITER'S ZODIACAL REALM

A GAS GIANT'S ODYSSEY. The solar system's largest planet takes 11.86 years to circle the Sun. It thus spends on average nearly one year every orbit in each of the 13 constellations of the ecliptic, the Sun's apparent path across the sky caused by Earth's orbital motion. But when Jupiter crosses from Aquarius into Capricornus in August 2021, it will stay there for just four months before returning to Aquarius. The chart shows the percentage of time the giant planet will reside in each constellation from August 2021 until it returns to the same position five orbits from now, in December 2080. – RICHARD TALCOTT



ASTRONOMY: ROEN KELLY

FAST FACT

Jupiter's orbit tilts 1.3° to the ecliptic, enough that it slices through one non-zodiacal constellation: Cetus.

Dust to dust

Let's peer into the smoky veil that pervades the cosmos.

Dust grains within the dark Taurus Molecular Cloud-1 completely hide some background stars from view and redden the appearance of others. KEES SCHERER

Dust is the most common solid in the cosmos.

But don't knock it. After all, solid is an important attribute, being the preferred phase of matter for things like money, motorcycles, ice cream, and many of your other favorite items. That extends to astronomy, too. Even if gases are awesome when they conjure a Horsehead or a Lagoon, and liquids are intriguing due to their extreme rarity, many astronomers prefer solid things — at least, planetary scientists do.

Most solids are anonymous, like the million tiny asteroids roaming unseen between Mars and Jupiter, gaining notice only once every billion years when one gets gravitationally perturbed and crashes into Earth to suddenly let rats rule for a while. True, nature has created some noteworthy solids, such as the Crab Pulsar, which is so dense that it matches what you'd get if you crushed down a cruise ship — retaining every ton of its steel and leftover morsels of strip steak — into the volume of the tip on a ballpoint pen.

A ship's mass the size of a pen's point! Glimpsing such an ultradense solid might alone justify buying a telescope. Yet observers seeing it in the Crab Nebula rarely realize that 16th-magnitude central dot is a solid ball.

Nature's dominant solids are not pulsars or planets, but particles of dust.

Such visible solids are ultrarare beyond our own Kuiper Belt. But identifying the most plentiful ones should be easy. When we remember that the cosmos creates far more tiny objects than big ones — more minnows than whales and more viruses than heavyweight boxing champions — we ought to know that nature's dominant solids are not pulsars or planets, but particles of dust. And fine dust must be more prevalent than coarser varieties. That's why specks the size of the particulates in cigarette smoke rule the universe.

On Earth, however, we suffer from anti-dust prejudice. We scowl at the dirty coating on our primary mirror. We hate dust even if opticians warn us against this bias: "Leave your mirror alone," they plead, arguing that an ugly dust layer barely diminishes its light-gathering ability. Cleaning that mirror, on the other hand, is far more likely to harm it with fine scratches. "Ignore dust," they chant.

But not when we roam the cosmos. Out there, dust is cool. It scatters starlight with an attractive blue preference. Just as nitrogen and oxygen molecules scatter the Sun's blue light to fashion our azure day sky, dust particles create gorgeous reflection nebulae whose aureoles surround the Pleiades. They concoct the cobalt fringes of the Orion Nebula and mix with its crimson emissions to give us rare, psychedelic, deep-space purples.

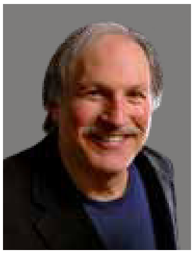
Then, after a star's blue light has been scattered away, the remainder, robbed of shorter wavelengths, appears reddish. Partially submerged behind dust clouds called absorption nebulae, distant suns look ruddy — alluring telescope targets that lurk behind that haze like mysterious faces in a smoky bar.

We all know that dust isn't equally apportioned. There's little between galaxies and in globular clusters. But you can't avoid it along the Zone of Avoidance, that wonderful old term for the Milky Way's plane. When we enjoy its inky Rorschach patterns through binoculars, we follow in the footsteps of early 20th-century dirt-patch enthusiasts like E.E. Barnard, whose dust catalogs are still used today.

Dust is also what we hunt when observing edgewise galaxies like NGC 4565 in Coma Berenices. "Can you see the dust lane?" we excitedly ask our telescope visitor. Their *yes* means they've passed our astro-fraternity's initiation ritual — except unlike the college version, they didn't have to run through campus stark naked. Instead, they nobly confirmed the blockading of untold stars by 400 billion trillion tons of smoke.

Let's end by finally exploring what dust is made of. Dust is either silicate or carbon based. In your bedroom, the dust in the air that settles at the rate of an inch (2.54 centimeters) an hour has many components, some of which are disgusting. There are countless minuscule human skin flakes and, if you live in a city, cockroach fragments. In space, where roaches are mostly confined to a few humid neighborhoods on Ganymede, analysis reveals that dust is always carbon based. And that carbon-based dust gives us the delicate, gauzy blue aura we see through our telescope eyepiece when we gaze at deep-sky targets.

Who'd have known dust could be so beautiful?



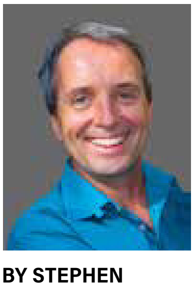
BY BOB BERMAN
Bob's newest book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**

A red meteor

Meteors that sport a ruddy glow are a rare breed.

A photo-illustration of the red meteor observed by the author from his home in Maun, Botswana.
STEPHEN JAMES O'MEARA



BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.

On the evening of April 12, 2021, while waiting for an exposure of the Milky Way to finish, I looked up to enjoy the beauty of the night and was rewarded with a heavenly gift: A reddish streak descending from a point nearly overhead in the area of Sextans.

Slowly, gracefully, it slipped south-southeast toward Centaurus, its ruby head appearing like a bloody teardrop. Extending upward from the head was a roughly 10°-long scarlet tail, which kept its length and color throughout the fall. The red meteor swept through the stars at an elegant pace for about five seconds before its head flared to rival Sirius in brightness, its leading edge glowing dimly yellow, while spitting out red and orange "sparks." Then, as soon as it flared, poof, the apparition vanished about 20° above the horizon. No smoky train was seen.

In the six decades I've been observing the sky, I had never seen such a rich red color in a meteor, nor such a slow and graceful spectacle against a dark starlit sky. As far as meteors go, its brightness was not magnificent and it did not blaze and burn like a fireball, but it was stunning nevertheless!

I had never seen such a slow and graceful spectacle against a dark starlit sky.

Historical accounts

A cursory search for reports of red meteor sightings turned up several cases sharing similar characteristics. For instance, in the October 1894 issue of *Nature*, British astronomer Alexander Stewart Herschel reported how a bright meteor crossed the eastern sky at about 7:54 P.M. While Herschel saw only the light it cast on the ground and in the sky, "like a momentary weak red flash of lightning," a bystander close to him saw it "fairly well." He told Herschel the "shooting-star" was "red in colour, and broke up at last with a red flash, leaving no train of light or of sparks along the track which it had traversed."

In the March 1903 issue of *Nature*, J.E.C. Liddle of Basingstoke, U.K., reported seeing an "extremely slow" meteor that "dropped vertically downwards from Coma Berenices, its brilliancy keeping constant" during its five-second descent. Liddle estimated the meteor was equal to Sirius in brightness. He reported he initially mistook the meteor for Arcturus, "the resemblance being probably increased by its colour, which was reddish." He adds that the meteor "left no trail." He also thought it "appeared to 'wobble,'" though he suspected "that may have been an illusion."

The scarcity of such phenomena is alluded to in a report on meteor showers from 1870–1879, which appears in the 1880 *Monthly Notices of the Royal Astronomical Society*. In it, Henry Corder communicated that of the 5,800 meteors reported, only about 10 percent showed a distinct color, "the most usual being orange or red."

Code red

One reason for the infrequent appearance of color in meteors is that they need to be bright enough to stimulate the eyes' color-sensitive cone cells — but not so bright as to create strong contrast against the dark sky, which may wash color out. According to the American Meteor Society (AMS), meteors displaying colors in the blue to yellow part of the spectrum depend, in part, on the "dominant composition of a meteoroid … with certain elements displaying signature colors when vaporized." Sodium, for instance, produces a bright yellow color; nickel emits green; and magnesium burns blue-white.

Red meteors, on the other hand, are most likely the result of glowing air plasma — molecules of atmospheric nitrogen (N2) and oxygen atoms (O) emitting a red light. According to the AMS, the meteor's velocity also plays an important role, since "a higher level of kinetic energy will intensify certain colors compared to others." And, "while fast meteors frequently have a blue color," as the observations above suggest, slow meteors on the fainter end tend to show red or orange hues.

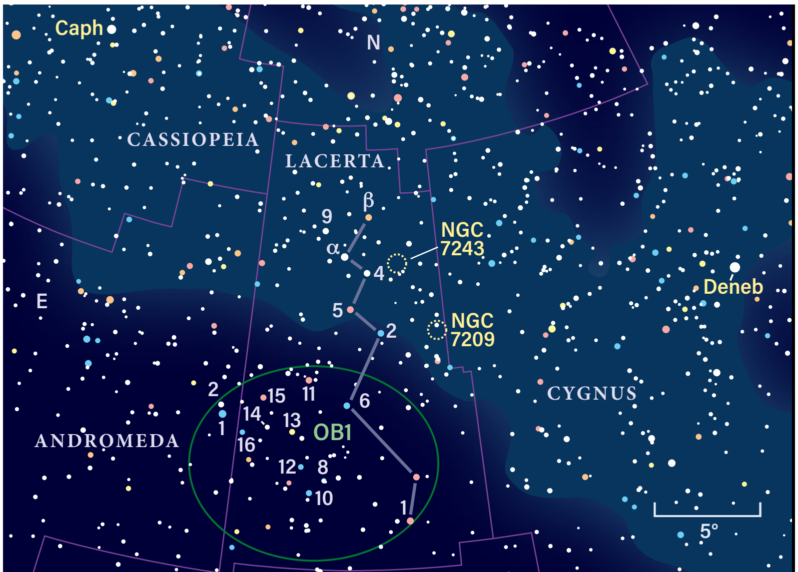
By the way, in Corder's notes on individual showers, he says that over 20 percent of Taurid meteors are colored, "usually orange and red." Taurid meteors can be seen any time during the months of September, October, and November — so keep watch.

Have you seen a red meteor? I'd be interested in hearing your tales, which you can send to sjomeara31@gmail.com.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara**

Leapin' Lizard

Scurry through the constellation Lacerta to find some hidden gems.



If observers take their time to explore this faint constellation, they're certain to find some treasures.
ASTRONOMY: ROEN KELLY

This month, the sky slowly begins to transition away from the summer stars to those of autumn. As it does, the arch of the Milky Way sweeps across the zenith down toward the northeast, curving through Cygnus on its way toward Cassiopeia. In between those two familiar constellations, the galactic plane passes through a barren zone lacking in bright stars. That's where we find the faint constellation **Lacerta** the Lizard.

As they were creating many of the early constellations, our ancestors ignored this area in favor of more obvious patterns. The Lizard didn't pop onto the scene until 1687, when 17th-century Polish astronomer Johannes Hevelius defined the constellation.

You will need dark skies to make out the Lizard's thin body, since the constellation's brightest star, **Alpha** (α) **Lacertae**, shines at only magnitude 3.8. The rest of the Lizard's sinuous form comprises stars between 4th and 5th magnitude.

You will need dark skies to make out the Lizard's thin body.

Lacerta also hosts a pair of open star clusters visible through binoculars, often missed because finding them can be a challenge. But with a little effort, we can coax them out of hiding.

We can use Alpha Lac as our jumping-off point. To get there, imagine a line connecting Deneb (Alpha Cygni) and Caph (Beta [β] Cassiopeiae), the western point in Cassiopeia's familiar W-pattern. Alpha Lac lies just south of the halfway point between the two. Alpha lies off-center in a stellar diamond formed by fainter Beta, 4, 5, and 9 Lacertae. The diamond fits neatly into the field of my 10x50 binoculars.

The diamond's southern facet, **5 Lacertae**, is a spectral type M subgiant. It adds a colorful ruddy hue to the otherwise white diamond. Studies show that 5 Lac is a spectroscopic binary, with a type A white companion orbiting it once in 42 years.

Open cluster **NGC 7243** is just 1.5° — the equivalent of three Full Moons stacked end to end — west of 4 Lacertae, the diamond's western facet. You'll first see it as a faint fuzz suspended against a pretty Milky Way field. Look carefully after bracing your binoculars for support, and you will be able to resolve a few feeble points of light peeking out from the cluster. Through my 16x70s binoculars, the star count increases to 10. The remaining members in the cluster's inventory of 40 lie below binocular limits.

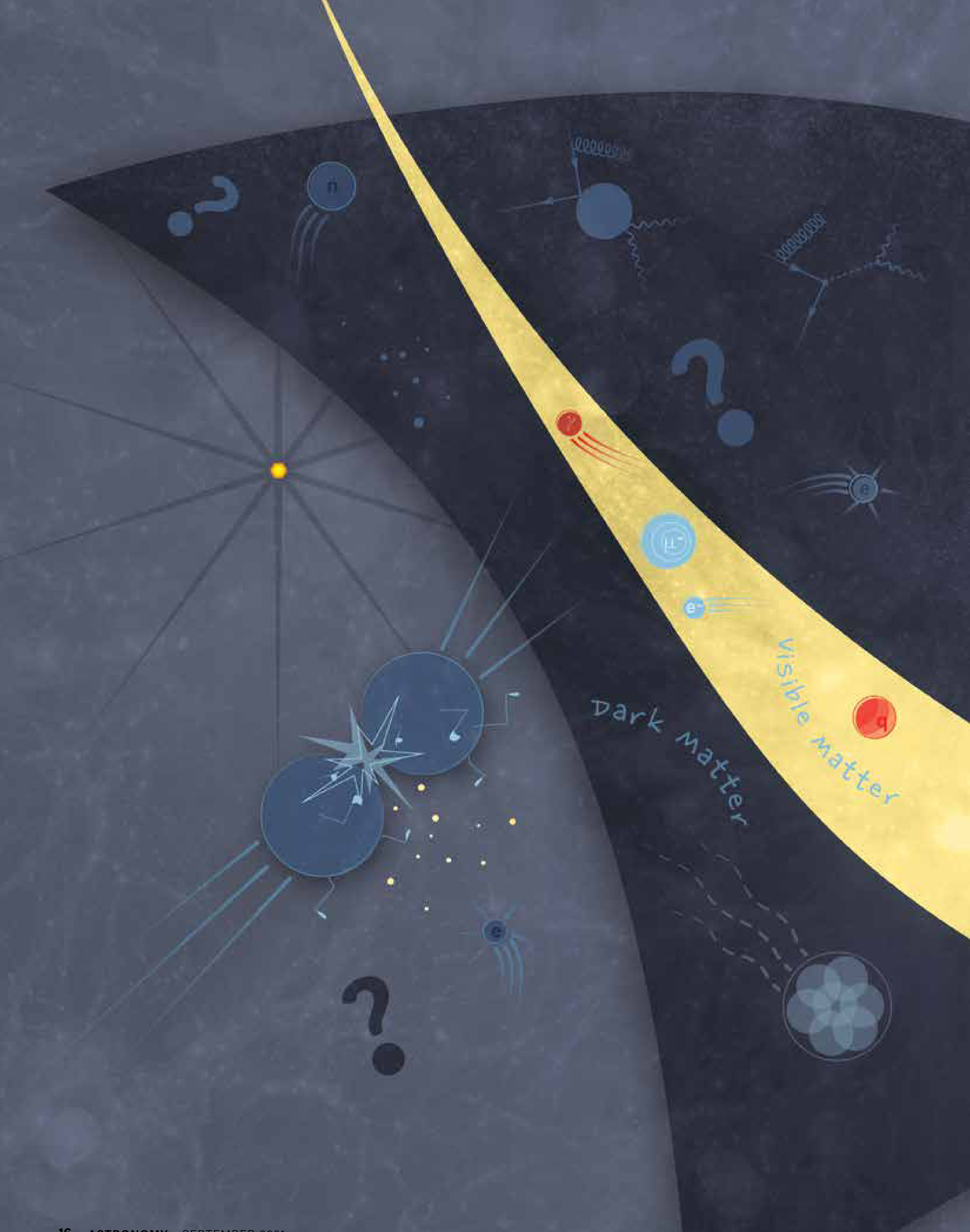
Lacerta also hosts a second open cluster visible through binoculars. **NGC 7209** is just inside the constellation's shared border with Cygnus. To find it, glance southwest of 5 Lac to the blue-white 5th-magnitude star 2 Lacertae. NGC 7209 is 2° to its west and just south of an orange 6th-magnitude star, HD 209857. NGC 7209 is a full magnitude fainter than NGC 7243, so spotting it may require some extra effort. Although NGC 7209 is credited with containing nearly 100 stars, only a half-dozen are bright enough to be visible through my 16x70s.

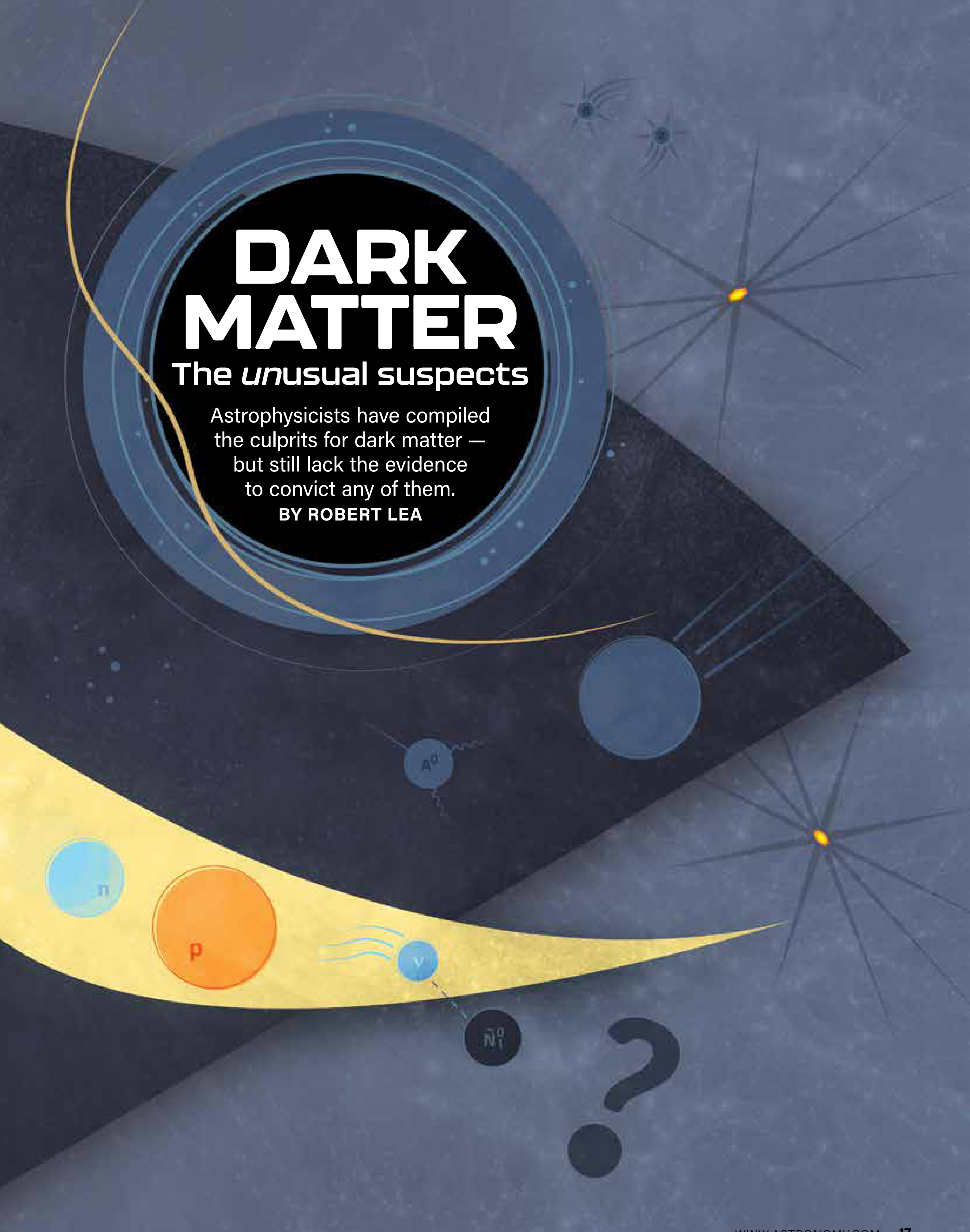
If you follow the Lizard's zigzaggy tail to its southern tip, you will come to a very pretty field of about 20 stars ranging in brightness from magnitudes 4.5 to 7, loosely gathered across 10°. These form the **Lacerta OB1** stellar association. A stellar association is a collection of searing class O and B stars more loosely structured than an open cluster. While they share a common origin and travel through our galaxy in the same general direction, their mutual gravity is not strong enough to hold the group together for long. At a distance of less than 1,300 light-years, Lacerta OB1 is among the nearest OB associations to our solar system. In order of descending brightness, members of the group include 11, 10, and 12 Lacertae; 2 Andromedae; 16 Lacertae; 6 Lacertae; and 8 Lacertae A and B. Those last two form a tight binary system near the southern edge of the association. At least 11x will be needed to resolve the pair. I would be especially interested in hearing from readers who resolve 8 Lac.

I welcome your questions, comments, and suggestions for future topics. Contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one.

BY PHIL HARRINGTON
Phil is a longtime contributor to Astronomy *and the author of many books.*

BROWSE THE "BINOCULAR UNIVERSE" ARCHIVE AT **www.Astronomy.com/Harrington**


Visible Matter
Dark Matter



DARK MATTER

The *un*usual suspects

Astrophysicists have compiled the culprits for dark matter — but still lack the evidence to convict any of them.

BY ROBERT LEA

Over the centuries, our understanding of the cosmos has grown by leaps and bounds. But it wasn't until relatively recently that astronomers discovered around 85 percent of the matter in the universe takes on a bizarre, foreign form: dark matter. Just like detectives in the best crime thrillers, astronomers must hunt for this puzzling substance by searching for subtle clues, sifting through convoluted evidence, and, critically, identifying likely suspects.

"Dark matter is the name scientists have given to the particles which we believe exist in the universe, but which we cannot directly see," says theoretical physicist Johar M. Ashfaque, a data scientist at the U.K.'s East Kent Hospitals University NHS Foundation Trust. Ashfaque first became interested in dark matter while earning a Ph.D. focused on string theory, at the University of Liverpool.

"This material appears to have mass, but it does not appear to absorb or emit any electromagnetic radiation," he explains. "Given the fact that it does not send us any light, it is not difficult to understand that it has been hard to discover anything about the nature of these mysterious particles."

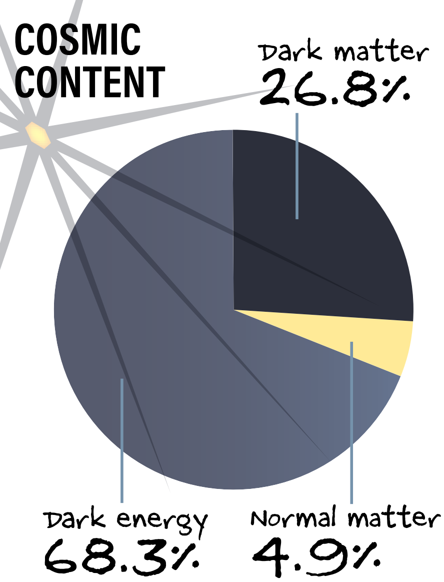
Despite dark matter's elusiveness, scientists have been able to shed some light on the problem. The majority of our knowledge about dark matter comes from the fact that although it doesn't interact with light, it does interact with normal matter via gravity. That's how we know it exists.

The collective gravity of all normal (baryonic) matter locked up in a galaxy's stars, planets, and gas isn't strong enough to bind that galaxy together as tightly as we observe. Without dark matter, astronomers would see stars on the outskirts of galaxies orbiting much more slowly than those near the center. Yet, starting with observations of the Andromeda Galaxy made by Vera Rubin and Kent Ford in the late 1970s, that's not what researchers have found. They instead see that visible matter at the outer edges of galaxies orbits faster than expected, suggesting galaxies contain an invisible form of non-baryonic (dark) matter.

Collecting evidence

Astronomers' meticulous identification of the indirect effects of dark matter is akin to police or private detectives gathering clues to help them identify the likely perpetrators. Of course, no murder mystery could possibly consider everyone a potential wrongdoer. First, investigators must narrow down the suspects. And that's the approach scientists have taken with dark matter.

Over the past several decades, researchers have managed to work out some of the characteristics of dark matter particles — specifically, the mass range in which dark matter candidates should fall. Physicists generally consider dark matter particles to have a mass between about 10^{-24} and 10^{28} electron volts (eV). That's a huge range, and it admittedly doesn't narrow down the suspect list very much. To put these masses into context, recent measurements of neutrinos — particles so light that hundreds of thousands of them stream through your body every second with no discernible effect — put them at a mass of roughly 1 eV. So, dark matter particles could fall anywhere on a wide mass range that spans from fantastically lightweight to superheavy particles like primordial black holes. Still, several experiments that are combing the cosmos for dark matter particles have managed to narrow down their potential masses even further, at least for specific hypothesized particle types.

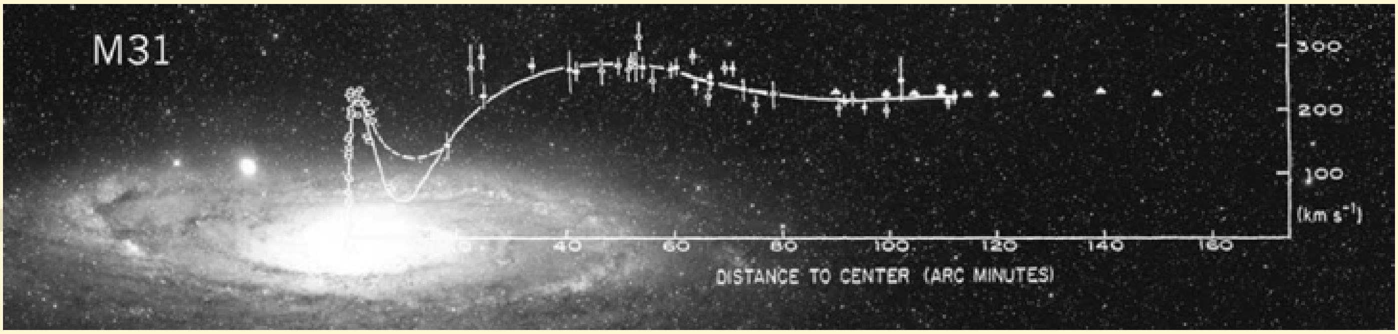


Knowing the mass range of potential dark matter candidates is valuable because mass and energy are intimately related. Their connection comes via mass-energy equivalence, which is a key consequence of Einstein's famed formula, $E = mc^2$. So, by having good estimates of the masses of dark matter particles, researchers know the energy ranges in which they should search for them. It's like a detective studying footprints left behind at the crime scene to estimate the size of the perpetrator and help map the areas they frequented.

Rounding up the regulars

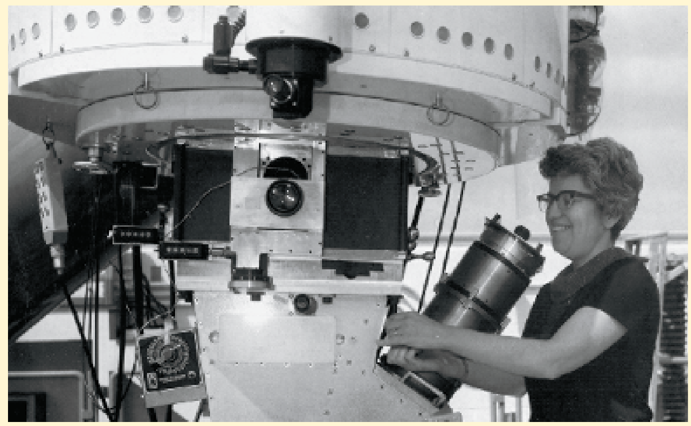
Mass alone, however, is not enough to pin down the particles responsible for dark matter. By examining other characteristics of the suspected culprits, such as how they interact with the known forces of nature, scientists can tighten the net even more. And although many of the most probable candidates for dark matter are hypothetical particles, their theorized existence is still based on real evidence compiled over the decades.

The possible forms of dark matter are typically divided into two categories: cold dark matter (CDM) and hot dark



Vera Rubin and Kent Ford discovered that observable matter near the outskirts of the Andromeda Galaxy (M31) rotates faster than it would if the galaxy were only composed of regular matter. This view of M31, captured by the Palomar Sky Survey, is superimposed with a plot of the radial velocities of both optical (dots) and radio (triangle) sources in M31. If the galaxy contained no dark matter, these velocities would significantly decrease with increasing distance. VERA RUBIN AND JANICE DUNLAP

Rubin (left) and Ford (white hat) check on their equipment at Lowell Observatory in 1965 during one of their first observing runs together. CARNEGIE INSTITUTION, DEPARTMENT OF TERRESTRIAL MAGNETISM



Rubin operates the 2.1-meter telescope at Kitt Peak National Observatory. Ford's spectograph is attached to the telescope so they can measure the radial velocities of matter at different distances from galaxies' centers. NOAO/AURA/NSF

matter (HDM). However, these category names don't refer to temperatures. They refer to speeds, with HDM particles traveling at nearly the speed of light and CDM particles moving at much slower, non-relativistic speeds.

One oft-proposed CDM candidate is weakly interacting massive particles, or WIMPs. These hypothetical particles are dubbed "weak" because they only interact through two of the four fundamental forces: the weak nuclear force and the gravitational force. WIMPs don't interact with anything through either the strong nuclear force or the electromagnetic force — something we know is also true for dark matter.

Joel Primack, an emeritus physics professor at the University of California, Santa Cruz, says, "Heinz Pagels and I were the first to point out in our 1982 article in *Physical Review Letters* that the lightest supersymmetric partner particle is a natural candidate to be dark matter. … And the lightest supersymmetric partner particle would be a WIMP."

Still, if astronomers want to prove WIMPs are responsible for dark matter, they need to catch them red-handed. WIMPs might provide clues about their existence by occasionally bumping into ordinary matter and, via the weak nuclear force, making those atoms emit light that can be picked up by extremely sensitive instruments. Yet despite multiple searches, direct evidence of WIMPs remains elusive.

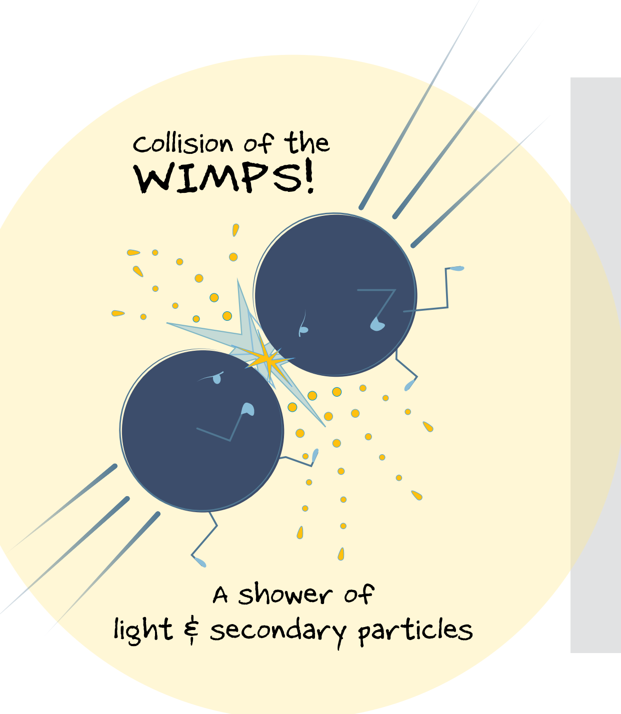
SUPERSYMMETRY AND DARK MATTER

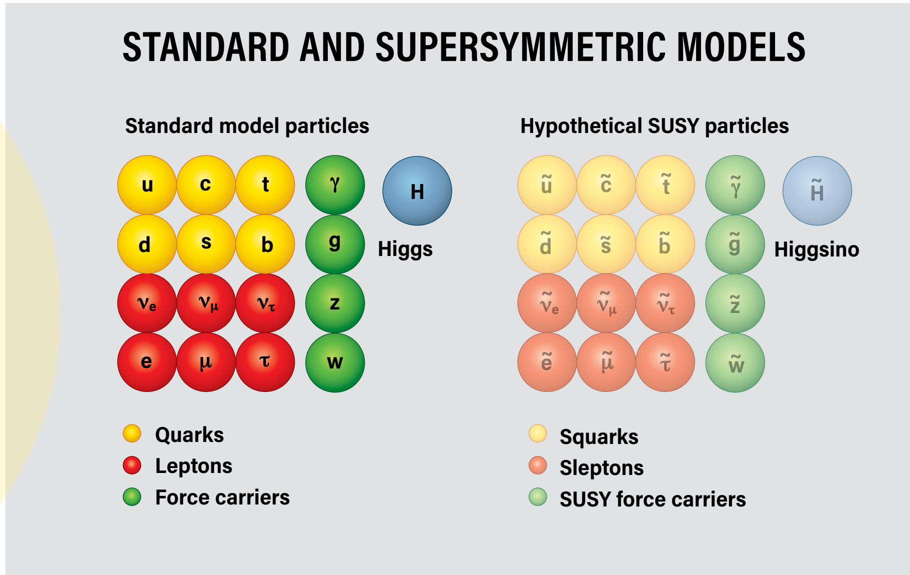
Supersymmetry (SUSY) is an extension of the standard model of particle physics that aims to fill some gaps within the model. SUSY leads to Grand Unified Theories, or theories of everything, that unite quantum mechanics and general relativity.

One of the most significant takeaways of SUSY is the idea that all particles in the standard model have a supersymmetric partner. So for quarks, there are squarks. Leptons are reflected by sleptons. And force-carrier particles, like photons for electromagnetism, have SUSY counterparts, too. This model extension exists primarily to explain how the Higgs boson can interact with all particles to give them mass, yet still remain so light itself. The supersymmetry particles allow for a light Higgs boson and an equally light SUSY counterpart, the Higgsino.

How does this connect to dark matter? Of all of the hypothetical particles suggested by SUSY, one, the so-called lightest supersymmetric particle (LSP), could be responsible for dark matter's effects. Certain theories predict that this LSP wouldn't decay into a particle in the standard model. And if the LSP exists, it must be electrically neutral, or it would be captured by Earth's magnetic field and reveal itself. This would mean the LSP lingers around the universe, not interacting with much. And when it does, it only does so via gravity, like dark matter.

Still, there is no experimental evidence of supersymmetry, and thus no evidence of the LSP. But if supersymmetric particles exist, they should eventually reveal themselves in particle collisions conducted at facilities like CERN's Large Hadron Collider (LHC). And thanks to recent upgrades, physicists will soon witness more collisions than ever, upping the odds of spotting rare particles. This makes the LHC and future particle accelerators vital tools for investigating dark matter. *—R.L.*





Researchers have already found some indirect evidence, though. When two WIMPs collide, they don't just bounce off each other or pair up. They obliterate each other in a powerful burst of pure energy. "Gamma rays from the center of the Milky Way nicely fit the predictions of WIMP annihilation," Primack says. Still, he cautions, "there are other possible explanations," as similar emissions are caused by high-energy cosmic rays and other types of particle collisions.

Another potential line of indirect evidence comes from physicists who run simulations of the early universe. These computer-generated universes commonly see WIMP lookalikes pop up and survive to the modern day, and their numbers are close to the abundances physicists predict based on our current understanding of dark matter.

Yet, by and large, astronomers can't seem to inextricably tie WIMPs to dark matter. This is because physical processes like interactions through the weak force and annihilation are extremely rare. Pinning dark matter on WIMPS is a tall order that requires detectors housed deep beneath Earth's surface to block out cosmic noise. One such detector is the Large Underground Xenon (LUX) experiment, which aims to detect WIMPs using canisters of xenon located 5,000 feet (1,500 meters) below ground in South Dakota.

Sterile neutrinos

Unlike WIMPs, scientists have had success detecting neutrinos, which are chargeless, near-massless particles that share the weakly interacting properties of WIMPs. However, because neutrinos travel at nearly the speed of light, they don't fit the CDM model. Still, that doesn't rule out neutrinos as an HDM candidate.

Some physicists have hypothesized that the various known flavors of neutrinos (electron, muon, and tau neutrinos) have a much more massive cousin: the sterile neutrino. These particles would likewise barely interact with regular matter and ignore electromagnetic influence, but they might also have enough mass to account for dark matter.

Despite their heft, sterile neutrinos should be trickier to collar than common neutrinos, as the latter are abundantly produced by stars, including the Sun. While standard neutrinos occasionally interact with ordinary matter via the weak force and gravity, sterile neutrinos would only interact through the latter. And because even sterile neutrinos would be relatively low-mass particles in the grand scheme of things, observing their tiny gravitational effects is extremely challenging.

This challenge, however, could be lessened in the very near future. In April 2021, researchers at the KArlsruhe TRitium Neutrino Experiment (KATRIN) narrowed down the search for the sterile neutrino by reducing the range of the particle's proposed mass to less than 1 eV. KATRIN will continue to seek evidence of sterile neutrinos by observing the radioactive decay of protons within heavy water to neutrons, with each event releasing an electron and a neutrino. The larger the mass of the released neutrino, the less energy the released electron has. So, if sterile neutrinos are occasionally emitted during the decay process, researchers should be able to detect a discernible signal in the energy spectrum of the released electrons.

Although WIMPs and sterile neutrinos share some notable features with our mugshots of dark matter, not all possible dark matter suspects have to be heavyweights like them.

Axions: The featherweights

For years, WIMPs were the uncontested frontrunners for dark matter. But more recently, another type of particle, first theorized in the 1970s, is becoming a stronger contender in physicists' minds. These particles — dubbed axions after a popular brand of detergent (because they would clean up the dark matter problem) — are similar to photons. But whereas photons are massless, axions still possess a tiny amount of mass, perhaps a billionth the mass of an electron.

Searching the universe for such lightweight particles may be akin to dusting the entire planet for a single fingerprint, but that's basically what's occurring at the Axion Dark Matter eXperiment (ADMX) underway at the University of Washington. The ADMX G2 project depends on an axion helioscope, which uses a powerful magnetic field to convert

The LUX detector, seen here during the assembly process, relies on photomultiplier tubes that can detect photons emitted during collisions between dark matter and xenon nuclei. MATTHEW KAPUST/SURF

Riding atop a large transport vehicle, KATRIN's enormous 200-ton spectrometer makes its way through the narrow streets of the German village Leopoldshafen in late 2006. Altogether, this essential component of the neutrino-hunting experiment traveled some 5,600 miles (9,000 km) over the course of more than 60 days to reach its final destination at nearby Karlsruhe Research Center. KARLSRUHE TRITIUM NEUTRINO EXPERIMENT

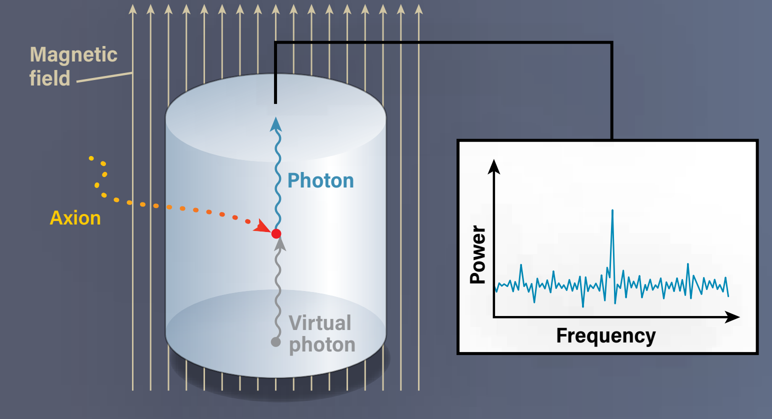
dark matter axions into microwave photons. While the researchers haven't yet managed to spot an axion (you would be reading a very different article if they had), like the KATRIN team has done for neutrinos, the ADMX team has placed important constraints on the possible mass range of axions. This enables other scientists to limit their searches to ever-narrower energy ranges.

Despite being exceptionally tiny and light, axions could account for the massive gravitational influence of dark matter, as long as they are packed incredibly tightly throughout the universe. Axions are also one of the most interesting candidates for dark matter partly because their existence could simultaneously solve another troubling mystery in physics: They might explain why the early universe seemed to favor matter over antimatter, despite the two initially existing in equal amounts. This is called the charge parity (CP) violation problem, and axions could fix it.

The temptation of killing two birds with one stone has only served to bolster theorists' desire to add axions to the short list of possible dark matter suspects. "The axion is the best solution to preventing CP violation," says Primack. But he also warns against settling for an answer out of convenience: "[Axions] could do that and still make no significant contribution to the dark matter density of the universe."

Despite understandable caution, Primack thinks axions could be a leading contender for dark matter. "Axions and

DETECTING AXIONS WITH ADMX

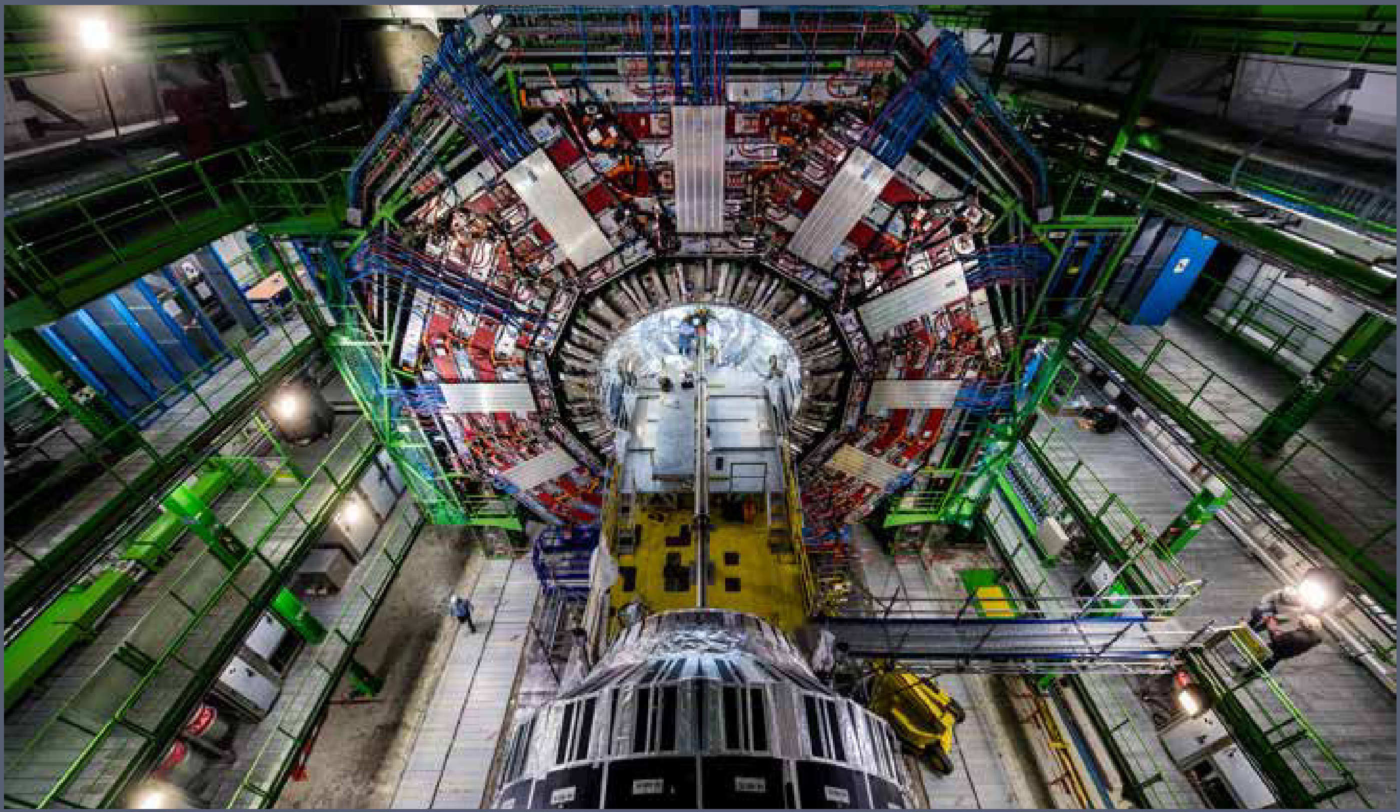


The Axion Dark Matter eXperiment (ADMX) relies on a strong magnetic field streaming through a cylindrical cavity to hunt for the dark matter candidates. If the theory of axions is correct, a sensitive microwave receiver should be able to pick up a faint boost in power generated within the cryogenically cooled and tunable microwave cavity when an axion converts into a photon. *ASTRONOMY*: KELLIE JAEGER AFTER C. BOUTAN/PACIFIC NORTHWEST NATIONAL LABORATORY/APS/ALAN STONEBRAKER

BREAKING THE LAW! CP VIOLATION

The universe abounds with matter, yet is relatively lacking in antimatter. This disparity must have started early in the cosmos' history because if the ratio of matter to antimatter were exactly equal, they would have completely annihilated each other long ago. That would have left a universe devoid of matter in any form, leaving only energy behind. Yet, billions of years after the Big Bang, the cosmos is still filled with plenty of regular matter.

The thinking goes that some hidden force (and associated field) might explain the matter-antimatter imbalance of the early universe. The axion was originally suggested as a particle emerging from this field by the independent teams of Roberto Peccei and Helen Quinn, and Frank Wilczek and Steven Weinberg. —*R.L.*



Physicists and engineers work to replace the pixel detector of the Large Hadron Collider's Compact Muon Solenoid (CMS) experiment in this image, taken March 7, 2017. More recently, the LHC received new high-luminosity upgrades, giving it a greater chance to spot rare particles like X17. MAXIMILIEN BRICE/CERN

REASONABLE FORCE?

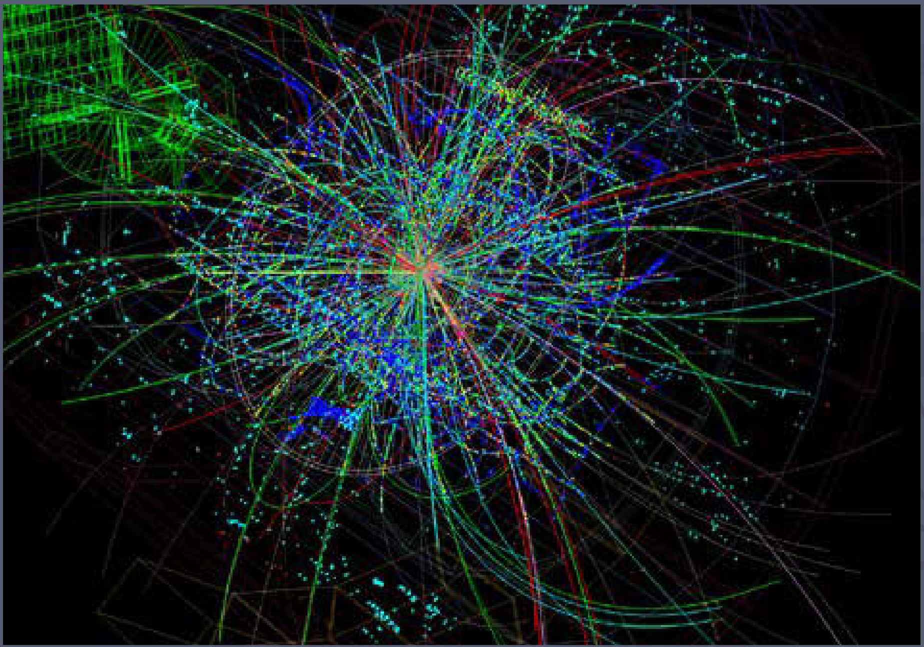
CONNECTING DARK MATTER TO A FIFTH FORCE

Physicists aren't just considering subatomic particles as possible culprits for dark matter. For instance, various versions of MOdified Newtonian Dynamics (MOND) attempt to revise our well-tested theory of gravity to account for dark matter's perceived effects. Perhaps the issue isn't that scientists misunderstand how gravity works, but rather that there exists an unknown fundamental force.

The four known fundamental forces depend on force-carrying particles called bosons. Photons act as the boson for electromagnetism. Gluons are responsible for the strong nuclear force. W and Z bosons serve the weak force. And physicists believe the gravitational force is carried by gravitons, though these particles have yet to be detected.

Gravity doesn't play well with the other known forces, though — at least, not on the tiniest of scales. And some think this could be because we're missing a force altogether. This hypothetical fifth force would also need a force-carrying boson, which is provisionally named X17 and would sit outside the standard model.

In 2003, researchers showed that a particle similar to X17 would weakly communicate forces between dark matter particles in a way that is similar to how photons interact with baryonic matter particles (hypothetically, at least). There is some limited evidence of X17's existence, mainly from observations of the decay of beryllium and helium isotopes made by the NA64 experiment team at CERN's Super Proton Synchrotron (SPS) particle accelerator. Yet the existence of X17, and thus a fifth force of nature, is still far from confirmed. Fortunately, the Large Hadron Collider (LHC) might turn up evidence of X17 when its upgraded LHCb experiment, which seeks another particle called the beauty quark, restarts in 2023. *—R.L.*



Particle tracks are shown here emanating from the first high-energy collision between a proton and a lead ion at the LHC in 2012. By analyzing the plethora of particles produced in such collisions, researchers are continuously working to unravel the many mysteries of the standard model. P. CHARITO/WIKIMEDIA COMMONS

supersymmetric WIMPs remain the two candidates that are motivated by non-cosmological arguments," he says, "and they have the virtue that they interact with ordinary particles — and are thus detectable."

Don't leave town

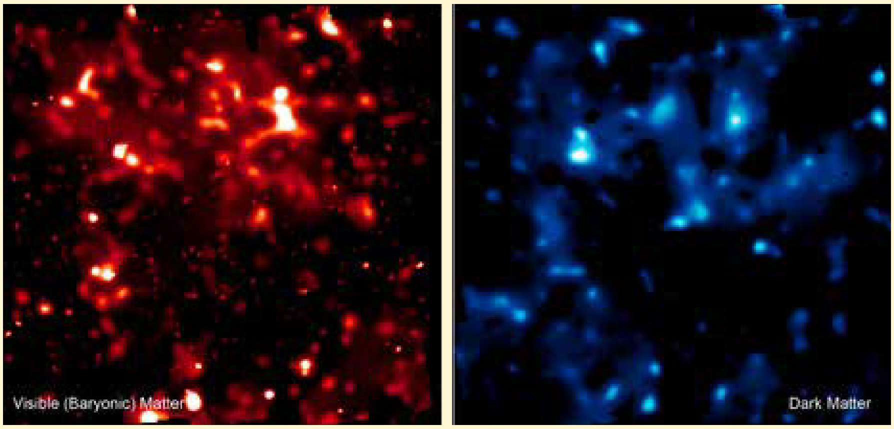
Unlike the current favorites, some former dark matter candidates aren't hypothetical, or even all that strange. But just as detectives release suspects with strong alibis, astronomers and physicists have had to clear multiple particles of interest from any definitive involvement with dark matter.

One example: massive astrophysical compact halo objects, or MACHOs, which include the invisible (to us) remnants of dead stars like some white dwarfs and neutron stars, stellar-mass black holes, and even failed stars like brown dwarfs. These bodies are still composed of regular matter, so although their matter might be exotic by Earth standards, it still interacts with the fundamental forces in predictable ways. The only reason we can't see MACHOs is that their light-producing processes have ceased (or never started in the first place) or are so reduced that we can't detect electromagnetic radiation from them.

Still, MACHOs have largely been ruled out as dark matter because the mass estimated to be locked up in these objects isn't sufficient to account for the strength of dark matter's observed gravitational effects. Thus, if dark matter was actually composed of MACHOs, these objects would need to be much more prevalent than astronomers currently calculate.

Another explanation for dark matter that has fallen out of favor over the years posits that the substance doesn't exist at all. These so-called MOdified Newtonian Dynamics (MOND) theories suggest dark matter is merely a cosmic illusion, a result of our flawed understanding of how gravity works on the grandest scales.

But MOND theories have so far faltered because, while they can account for many dark matter-related phenomena, they can't explain all of dark matter's observed effects. So, even if we were to modify our well-tested theories of gravity, astrophysicists would still be missing a major piece of the dark matter puzzle.



These false-color images captured by the Hubble Space Telescope compare the distribution of normal matter (red) to dark matter (blue) in the universe. The map covers an area of the sky nine times larger than the Full Moon, making it one of the best maps of dark matter ever obtained. NASA/ESA/R. MASSEY

"None of the attempts to [explain dark matter's effects] without dark matter, such as MOND, have succeeded," Primack says. "At best, they explain a small fraction of the observational data." So, for now, MOND and MACHOs seem to be off the hook.

Other alternative explanations for the effects of dark matter include a fifth fundamental force of nature or clusters of tiny primordial black holes left over from the earliest moments of the universe. But, yet again, both of these theories have problems.

As of yet, there is little evidence to suggest a fifth fundamental force of nature. Meanwhile, primordial black holes, which would have been created by gravity fluctuations in the very early universe, sound like promising candidates for dark matter. That's because, like any black hole lacking a glowing accretion disk around it, they don't produce light. Plus, if primordial black holes are as lightweight as some theories predict — holding as little as 1/100,000th the mass of a paperclip — they wouldn't create any of the violent effects that astronomers depend on to catch their more massive counterparts. The main evidence for primordial black holes currently comes from high-pitched gravitational-wave signals picked up by the Laser Interferometer Gravitational-wave Observatory. Yet these signals can also be easily explained by other known phenomena.

Homing in

The dark matter mystery may not yet be solved, but intrepid cosmic sleuths have compiled mug shots of the likely suspects, as well as confirmed alibis for some others. It now seems it's only a matter of time before researchers are able to pin dark matter on the right culprit.

In fact, the net could already be closing. In early 2021, a team from the University of Sussex in the U.K. revealed that they had managed to narrow the potential mass range of dark matter particles to between 10^{-3} and 10^7 eV. Not only is this a significantly trimmed range, it also rules out both ultralight particles and their supermassive counterparts. The researchers culled this new energy range by considering the effects of quantum gravity. However, quantum gravity is still purely hypothetical, so the newly constrained range needs much more evidential support before it is widely accepted.

There also remains the possibility that the true explanation for dark matter is something scientists haven't yet dreamed up. And in that case, 85 percent of the mass in the universe might remain incomprehensible for years to come.

"The nightmare about dark matter is that it might be a kind of particle that doesn't interact even weakly with ordinary matter, except by gravity," Primack says. And that, he adds, "would make it undetectable." If indeed this turns out to be the case, dark matter just might be committing the perfect cosmic crime.

Robert Lea *is a freelance science journalist based out of Liverpool in the United Kingdom.*

The Tarantula Nebula is one of the most stunning objects in the southern sky: a vast web of gas shrouding stars bursting into life. Studying them could be key to understanding conditions in the early universe. ESO

Untangling the Tarantula Neb

This vast cosmic cloud gives us a spectacular close-up view of stars bursting into life. BY RICHARD TALCOTT

IN 1799, FRENCH SOLDIERS unearthed a large black rock near the Egyptian town of Rosetta (now Rashid) in the Nile delta. Inscribed on its flat face were three versions of a single decree from 196 B.C. affirming the royalty of 13-year-old Ptolemy V: one in ancient Greek, one in the everyday language of the Egyptian people, and one in hieroglyphs. The Rosetta Stone provided the key for understanding ancient Egyptian hieroglyphics, and ultimately the great civilization that created them.

Some 50 years before Napoleon's troops found the Rosetta Stone buried in the ground, another French explorer made an equally stunning discovery not beneath their feet, but above their heads. In 1751, astronomer Nicolas-Louis de Lacaille was surveying the deep southern sky from the Cape of Good Hope through his ½-inch refractor when he stumbled upon a small nebula. The object resided near the northeastern edge of the Large Magellanic Cloud (LMC), the immense nebulous region that astronomers now recognize as a satellite galaxy to the Milky Way.

Lacaille cataloged it as a "Nebula of the first kind," meaning he could not see any star in the nebula through his telescope. In his 1801 star atlas *Uranographia*, German astronomer Johann Bode referred to it as 30 Doradus, reflecting its position in the constellation Dorado the Dolphinfish. It wasn't until the 20th century that deep photographic exposures taken through large-aperture scopes revealed the object's spidery tendrils of glowing gas that inspired its common name: the Tarantula Nebula.

Big, bright, and beautiful

The Tarantula is a giant stellar nursery in the midst of transforming a massive reservoir of mostly hydrogen gas into hundreds of thousands of stars. The biggest of these newborn suns are among the most massive known, and they burn hot and bright, ionizing the surrounding gas and causing it to glow with a characteristic reddish color.

Although you can use words like *big* and *bright* to describe the Tarantula, they really don't do it justice. The entire nebula spans roughly 1,000 light-years. For comparison, the


ula

Milky Way's Orion Nebula (M42), the finest example of a star-forming region visible from mid-northern latitudes, is a mere 25 light-years in diameter. And the Tarantula shines brightly enough to see with the naked eye from the Southern Hemisphere, despite lying some 160,000 light-years from Earth. By contrast, naked-eye M42 is but a stone's throw away at 1,500 light-years.

To put it another way, if you were to place the Tarantula at the same distance as the Orion Nebula, it would cover as much sky as 75 Full Moons placed side by side — enough to stretch 40 percent of the way from the horizon to the zenith. And it would be bright enough to cast noticeable shadows.

Even where it is, the Tarantula is still close to us in cosmic terms. And that makes it an enticing target for astronomers. "The Tarantula Nebula is the region of most intense star formation in the Local Group — a region within about 10 million light-years of the Sun that includes more than 80 galaxies," says astronomer Elena Sabbi of the Space Telescope Science Institute in Baltimore. "[It's] the only example of a starburst — an extremely intense and rapid episode of star formation — that we can study in detail."

> "The Tarantula Nebula is the only example of a starburst — an extremely intense and rapid episode of star formation — that we can study in detail."
>
> Elena Sabbi

In fact, astronomers wouldn't necessarily want the Tarantula to be any closer. Because it lies away from the dust-laden disk of the Milky Way, scientists have an unobscured view, allowing them to clearly see the objects within it. It's more difficult to study nearby star-forming hot spots — like the Orion Nebula and the Carina Nebula (NGC 3372) — because astronomers must view them through the dusty haze of our galaxy's disk.

"The Tarantula is close enough for us to study individual stars across the electromagnetic spectrum, from X-rays to infrared, as well as to consider it as a single nebula," says Paul Crowther of the University of Sheffield in the U.K. You have to look much farther to see similarly impressive star-forming regions, he adds, so astronomers can't resolve their individual stars and can study only their overall properties.

Untangling the Tarantula's web

The Tarantula has enthralled astronomers ever since Lacaille first laid eyes on it 270 years ago. But the tools needed to decipher the nebula's inner workings have a much shorter pedigree.

The Hubble Space Telescope has played a leading role in deciphering the Tarantula. Sabbi leads the Hubble Tarantula Treasury Project (HTTP), a multiwavelength survey that provides the most accurate census of the nebula's stars. "HTTP is a high-resolution survey that consists of several filters from the near ultraviolet, [which is] sensitive to the light coming from the hottest and most massive stars, to the near infrared, [which] can penetrate thick walls of dust and reveal where low-mass young stars are still growing," she says.

So far, the census includes 820,000 stars, ranging from monstrosities that tip the scales at more than 200 solar masses down to stars with just half the mass of the Sun. "Thanks to Hubble, we can study how high- and low-mass stars coexist, and if the powerful radiation coming from the massive stars modifies the normal evolution of their smaller companions," Sabbi says.

Another key player in the study of the Tarantula is the VLT-FLAMES Tarantula Survey. The survey, led by Chris Evans at the UK Astronomy Technology Centre in Edinburgh, Scotland, concentrates on the nebula's massive stars.

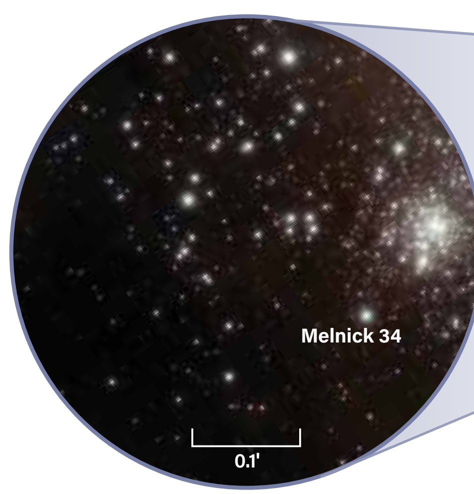
Evans and three of his colleagues hatched the idea for the survey in

ASTRONOMY: ROEN KELLY

A TANGLED WEB

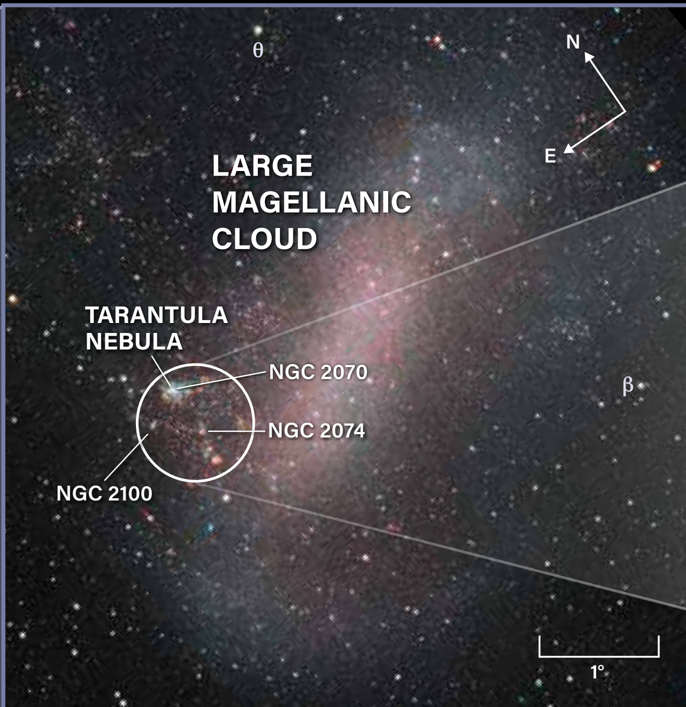
The Tarantula Nebula glows in visible and ultraviolet light in this composite image from the Hubble Space Telescope.

BOK GLOBULES: These dark, condensed gobs of gas are likely forming new stars.
PILLAR CHAIN: Astronomers think these structures are formed when shells of hot gas collapse in on themselves.
HODGE 301 is a star cluster that is home to some of the earliest denizens of the Tarantula's sprawling web.
NGC 2060 contains the fastest-rotating pulsar yet known, **PSR J0537-6910**, as well as the supernova remnant **N157B**.
VFTS 016 once belonged to R136, but this runaway star has put 375 light-years between it and its old system over the past 1.5 million years.
VFTS 102 holds the record for the fastest-spinning normal star yet known.

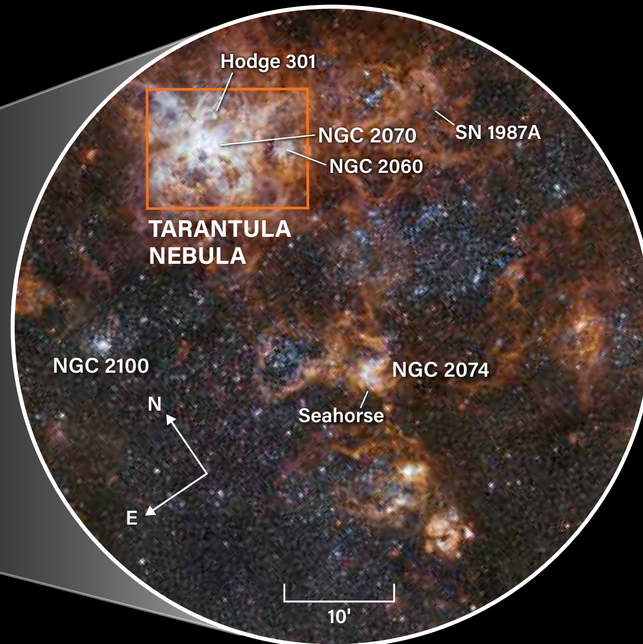


At the Tarantula's core, R136 brims with stars, including Melnick 34, the largest known binary system. This VLT image was produced with adaptive optics to reduce atmospheric distortion. ESO/P. CROWTHER/C.J. EVANS

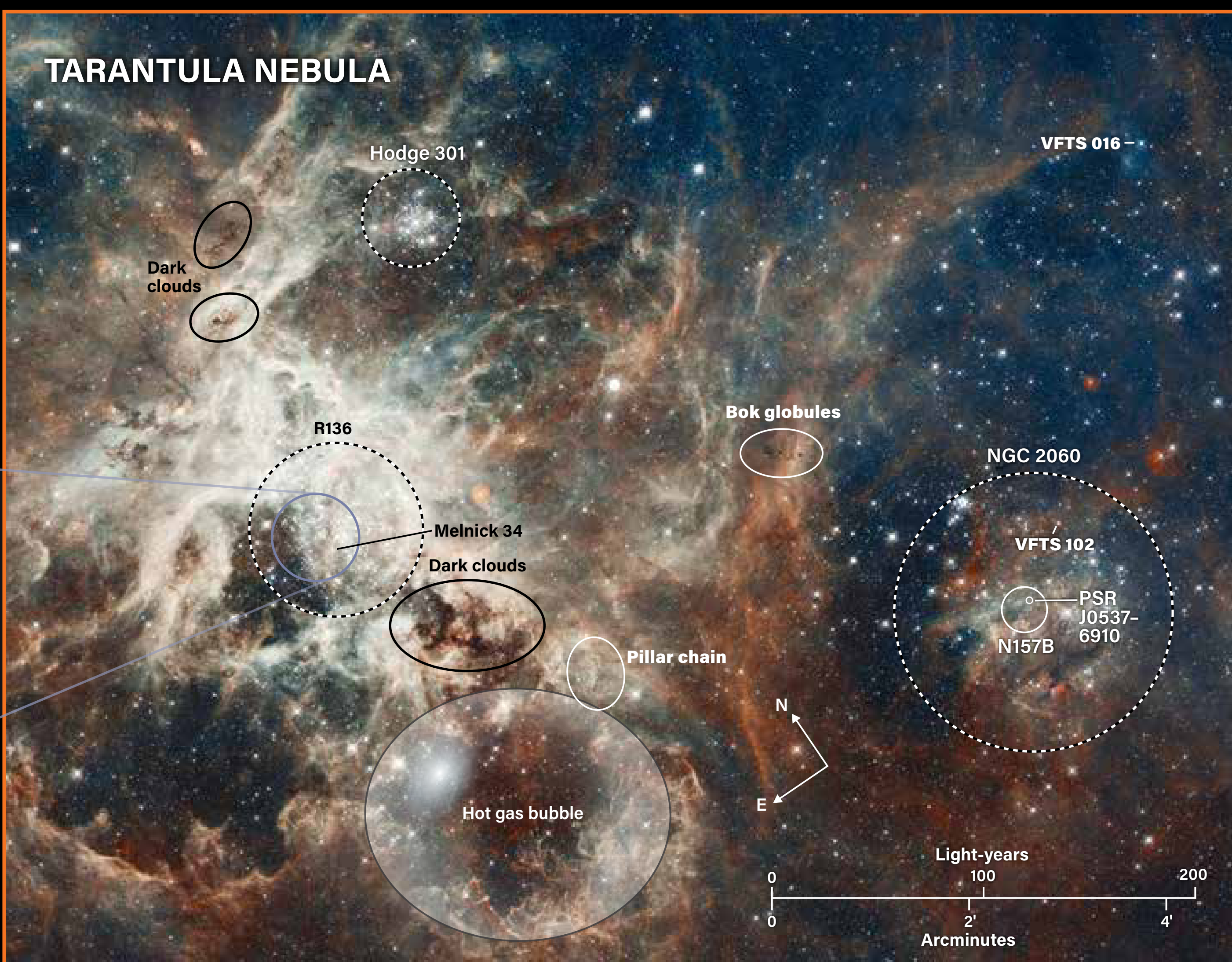
THE TARANTULA REVEALED



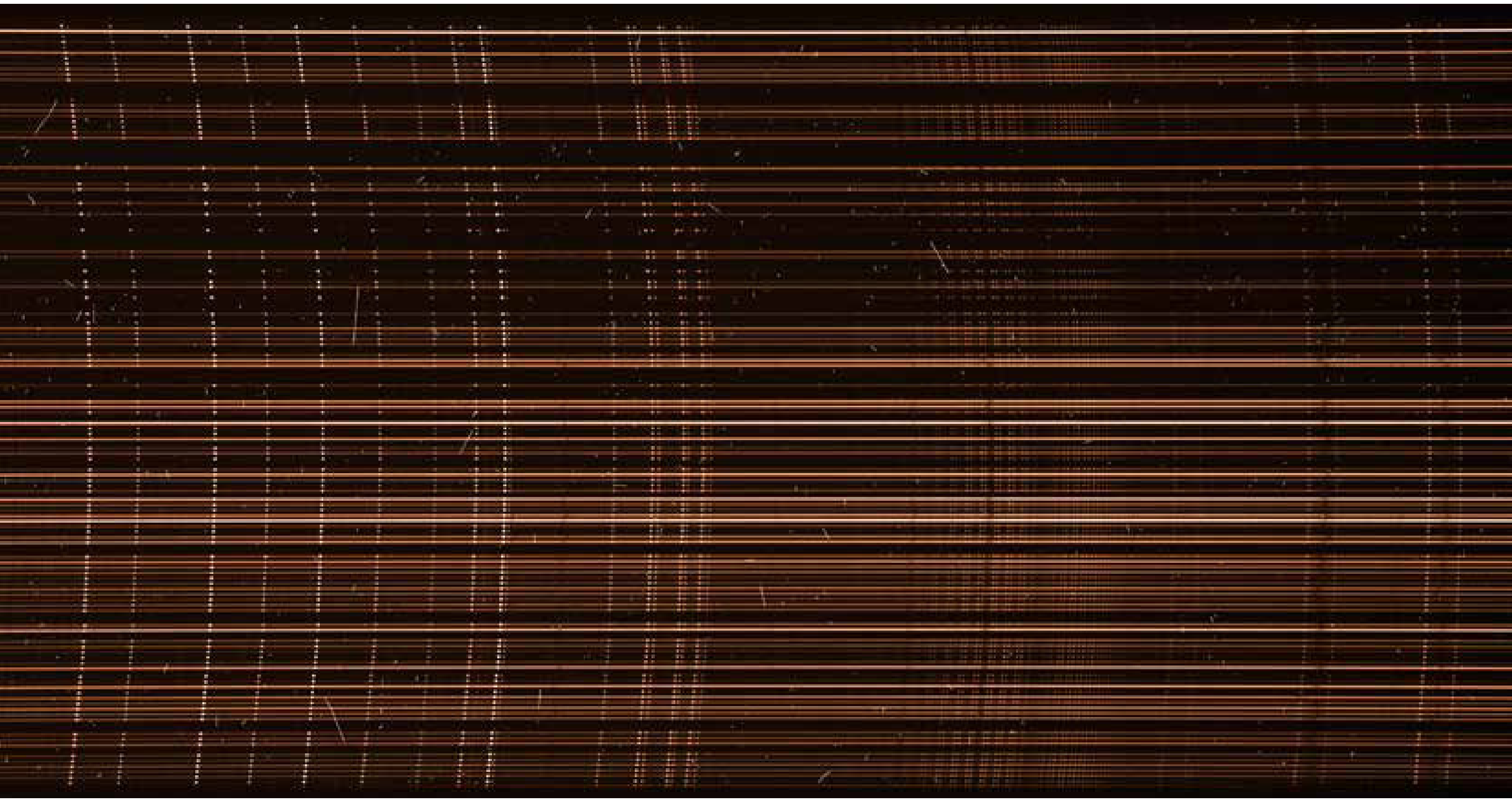
The Tarantula Nebula is the bright, weblike spot to the upper left of the Large Magellanic Cloud in this image from ESO's Visible and Infrared Survey Telescope. ESO/VMC SURVEY



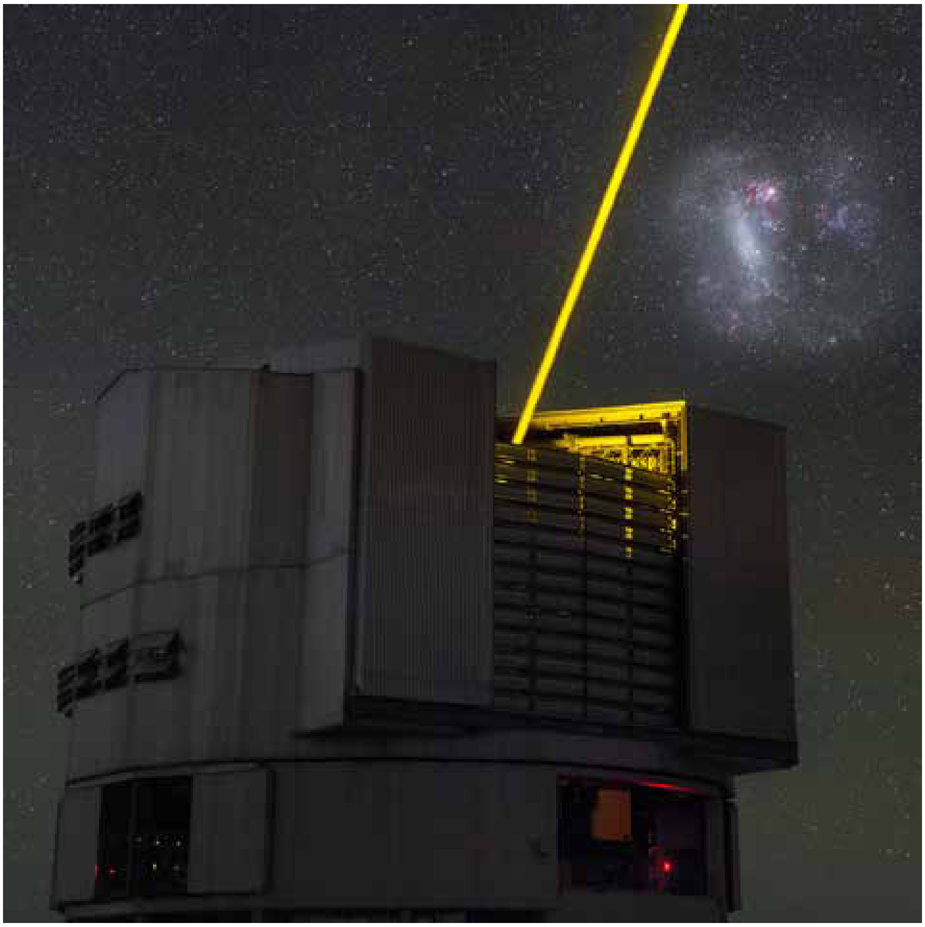
The remnant of SN 1987A, the nearest supernova to go off since Kepler's supernova in 1604, lies roughly 10' from the Tarantula. ESO



ASTRONOMY: ROEN KELLY, AFTER NASA, ESA, AND Z. LEVAY (STSCI); IMAGE: NASA, ESA, AND D. LENNON (ESA/HUBBLE)



This single raw image from the detector of the VLT's FLAMES spectrograph captures spectra from 130 individual stars. The spectrograph is fed by optical fibers that are positioned on a plate to capture the light of each star. ESO



One of the four telescopes that comprise ESO's Very Large Telescope array fires a laser beam into the night sky, creating an artificial guide star for its adaptive optics system. In the background looms the Large Magellanic Cloud; the Tarantula Nebula is the bright patch toward the top of the cloud. P. HORÁLEK/ESO

late 2007. They were in Utrecht in the Netherlands, attending a meeting of researchers studying massive stars in the Milky Way and the Large and Small Magellanic Clouds using the Fibre Large Array Multi Element Spectrograph, or FLAMES. The instrument can target more than 100 objects at a time, splitting the light from each one into its own spectrum to reveal its physical properties.

Evans and his colleagues had been studying massive O-type stars, but they had precious few examples in their dataset. As they huddled at a local pub, a plan to enlist FLAMES began to take form.

"We came up with a working idea of: 'Let's try to do everything in the Tarantula,'" recalls Evans. "That would give us a sample size large enough to solve many of our problems." They mapped out a rough idea for the survey in the following weeks and then assembled a proposal for time to use FLAMES on one of the 8.2-meter telescopes of the European Southern Observatory's Very Large Telescope (VLT) array in Chile.

This comparison of images in visible and ultraviolet light (at left) and infrared light (at right) shows how infrared wavelengths can penetrate colder dust, revealing more young stars. NASA, ESA, F. PARESCE (INAF-IASF, BOLOGNA, ITALY), R. O'CONNELL (UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE), AND THE WIDE FIELD CAMERA 3 SCIENCE OVERSIGHT COMMITTEE

"FLAMES provides us with optical spectra of up to 130 objects simultaneously across a 25' field of the sky," says Evans. That's enough to cover a large fraction of the Tarantula. "This means that instead of obtaining spectra of stars one by one in such a rich part of the sky, we can make much more efficient use of precious VLT time." The observations yield the temperature, surface gravity, composition, rotation, and line-of-sight velocity of each star.

Into the spider's lair

The Tarantula may seem like a monolithic entity, but the surveys have helped to show it has many interrelated parts, with several distinct star clusters and multiple regions of nebulosity. At the nebula's heart lies the impressive star cluster Radcliffe 136 (R136). Until the 1980s, astronomers suspected that this intensely bright central region held a single supermassive star that weighed perhaps 1,000 Suns. That would be quite remarkable, not least because the laws of physics dictate that no such star could exist.

But as astronomers developed high-resolution imaging techniques and Hubble soared above Earth's distorting atmosphere, R136's true nature came into focus. It turns out to be a compact star cluster comprising dozens of O-type main-sequence stars — the hottest, brightest, and most massive stars that are still converting hydrogen into helium in their cores — and equally hot and massive Wolf-Rayet stars, which are characterized by ferocious stellar winds.

No other spot in the known universe contains as many of these stellar behemoths. "The Tarantula in general, and its dense star cluster R136 in particular, contain the most massive stars we have currently identified, with several dozen exceeding over 100 times the mass of our Sun," says Crowther. "The most extreme likely started their lives with 200 to 300 solar masses, but they have already slimmed down by 10 to 20 percent in the last million years or so because they shed weight at an amazing rate." The 10 brightest of these stars provide nearly 30 percent of the energy ionizing all of the Tarantula's gas.

The more massive a star, the shorter its lifespan. O-type stars live no more than a couple of million years before they exhaust their nuclear fuel and ultimately detonate as supernovae or implode directly into black holes. The abundance of these heavyweights in R136 suggests it is no more than 1 million to 2 million years old. Sabbi's team has also discovered a smaller, more diffuse clump of stars 15 to 20 light-years northeast of R136. This group has no O-type stars but does hold slightly smaller and cooler B-type stars, implying it is perhaps a million years older than its neighbor.

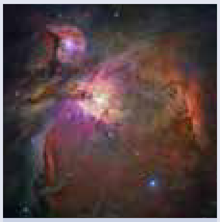
The density of stars in this region leads some scientists to speculate whether it might one day form a globular cluster. Although all of the globulars in the Milky Way are ancient, dating back to near the birth of our galaxy, the LMC holds many youthful lookalikes. The volume within about 65 light-years of R136 contains nearly 90,000 solar masses of material, close to the average size of Milky Way globulars.

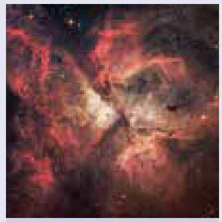
> "The Tarantula in general, and its dense star cluster R136 in particular, contain the most massive stars we have currently identified, with several dozen exceeding over 100 times the mass of our Sun."
>
> Paul Crowther

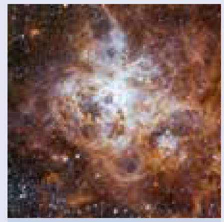
Seeing first light

Surrounding R136 lies NGC 2070, the

TALE OF THE TAPE







	ORION NEBULA (M42)	CARINA NEBULA (NGC 3372)	TARANTULA NEBULA
Distance (light-years)	1,500	7,500	160,000
Diameter (light-years)	25	260	1,000
Apparent magnitude	3.7	4.8	5.0
Absolute magnitude	–4.6	–7.0	–13.5
Stars at least 1 million times more luminous than the Sun	0	5	50

Northern Hemisphere observers proudly point to the Orion Nebula as a sterling example of a stellar nursery. Its glowing tendrils of hot gas enshroud a handful of sizzling young stars along with thousands of lesser suns yet to emerge from their natal cocoons. Yet those with a clear view of the southern sky recognize the Carina Nebula as Orion's superior. Still, neither Milky Way object comes close to matching the Large Magellanic Cloud's Tarantula Nebula: the biggest, brightest, and best emission region in the Local Group of galaxies.

ORION NEBULA: NASA, ESA, M. ROBBERTO (SPACE TELESCOPE SCIENCE INSTITUTE/ESA) AND THE HUBBLE SPACE TELESCOPE ORION TREASURY PROJECT TEAM; CARINA NEBULA: WAGNER AMARAL; TARANTULA NEBULA: ESO

brightest region of nebulosity in the Tarantula. This is where the bulk of the remaining hydrogen gas resides, and where stars currently are forming at a furious rate.

The Tarantula's environment isn't quite so hectic beyond NGC 2070's borders. The nebula apparently came to life 20 to 30 million years ago, when stars started to turn on some 145 light-years northwest of R136's current location. This initial surge gave birth to the star cluster Hodge 301. Tens of millions of years is plenty of time for the most massive stars to explode, and astronomers estimate between 40 and 60 supernovae have gone off here during the cluster's lifetime.

The explosions have had two distinct consequences. First, they have cleared out much of the gas and dust in Hodge 301, affording astronomers a reasonably crisp view of the cluster. Second, the expanding supernovae shock waves have compressed gas on the outskirts of NGC 2070, helping to jumpstart star formation there.

Dozens of stars in Hodge 301 (lower right) have exploded in supernovae and sent shock waves into the surrounding gas, compressing it and forming the filaments seen here. HUBBLE HERITAGE TEAM (AURA/STSCI/NASA/ESA)

The Tarantula's third major star cluster is NGC 2060. It lies about 290 light-years southwest of R136 and its stars formed roughly 4 million to 6 million years ago, placing it intermediate in age between R136 and Hodge 301. Although NGC 2060 looks rather dull compared to R136 and is not as well-defined as Hodge 301, it embraces some of the Tarantula's most notable citizens.

Top of the list has to be the X-ray pulsar PSR J0537–6910. This object formed when a massive star exploded about 5,000 years ago (as seen from Earth), leaving behind a rapidly spinning neutron star. Not only is this pulsar the most energetic one known, but it is also the fastest rotating young pulsar. It spins once on its axis every 16 milliseconds, more than twice as fast as the pulsar at the center of the Milky Way's Crab Nebula. The supernova remnant associated with the stellar explosion, N157B, also can be seen in NGC 2060.

The cluster likewise harbors the fastest rotating normal star, VFTS 102. The VLT-FLAMES survey found this star's equatorial regions spinning at a rate of 1.4 million mph (2.2 million km/h), or some 300 times faster than the Sun. The rapid rotation means VFTS 102's shape more closely resembles an M&M than a sphere.

These three regions tell only part of the Tarantula's story. Massive stars are spread across the entire region, with

some of them apparently flung from their birthplaces. VFTS 016, for example, is a massive runaway star located well to the northwest of NGC 2060. Discovered as a fast mover during the initial stages of the VLT-FLAMES survey, the team only managed to measure its line-of-sight velocity. Eight years later, the researchers used data from the European Space Agency's Gaia spacecraft to pin down its speed: 225,000 mph (360,000 km/h)! Its position and motion indicate it was ejected from R136 about 1.5 million years ago and has since traversed 375 light-years. The scientists suspect the star once belonged to a binary system that suffered a rogue encounter with a third star, launching it on its epic journey.

Bubbles of hot gas sculpt the Tarantula's sprawling filaments in this composite image. First, the stellar winds and supernova explosions emanating from R136 form shock waves that heat gas to temperatures of millions of degrees, seen here in blue by NASA's Chandra X-Ray Observatory. That hot gas then expands and pushes away cooler gas and dust, shown in red as imaged by the Spitzer Space Telescope. X-RAY: NASA/CXC/PSU/L.TOWNSLEY ET AL. INFRARED: NASA/JPL/PSU/L.TOWNSLEY ET AL.

Probe of the distant universe

Studying massive binary systems in the Tarantula was one of the motivating forces behind the VLT-FLAMES survey. The results are startling: "We estimate that at least 50 percent of our targets are in binary systems," says Evans. "Alongside complementary studies in our own Milky Way, this result has significantly changed our perspective on stellar evolution."

Close binaries can interact in many ways, he adds. Mass and angular momentum can be transferred from one star to the other, and eventually the two stars can merge. "This results in very different evolutionary paths than if [they were] born as single stars." Some of these systems may develop into binary black holes and ultimately merge, producing a torrent of gravitational waves like those from similar systems that astronomers began detecting in 2015. Not surprisingly, the current record holder for a massive binary system, Melnick 34, resides in the Tarantula. Each of its two components weighs in at about 120 solar masses.

The biggest opportunity to arise from the HTTP has been to study the lifecycle of a starburst from up close. "The Tarantula Nebula has been forming stars for the past 30 million years," says Sabbi. "The epicenter of star formation during this time has moved considerably, and we can see how powerful stellar winds and violent supernova explosions have shut down star formation in one region of the Tarantula, just to start it again a few hundred light-years away."

What has happened just recently in the Tarantula may be a window into the universe's early history. Casting their gaze outward, astronomers detect what seem to be similar starbursts in galaxies so distant that universal expansion has shifted their light far toward the red end of the spectrum. "The Tarantula's properties appear to be comparable to knots of intense star formation in young galaxies at high redshift, so it gives us a local clue to galaxy assembly in the early universe," says Crowther.

Using the Tarantula as a model for these systems offers one more advantage over any potential Milky Way counterparts: The Tarantula and the surrounding LMC have far fewer heavy elements than star-forming regions in our own galaxy. The amount of metals — astro-speak for elements heavier than helium that stars have cooked up over the eons — in the LMC is only half that of the Milky Way, making it much more similar to the more pristine material present in the distant, early cosmos. With the Tarantula, it's almost as if astronomers have stumbled on their own Rosetta Stone, and have started using it as a key to understanding the mysteries of star and galaxy formation.

Scientists have been fortunate to have front-row seats to the Tarantula's display. "We're lucky to be witnessing these fireworks when the Large Magellanic Cloud is on its closest approach to the Milky Way in the last billion years or so," says Crowther. Alas, the performance may not run that much longer. "Much of the gas from the original molecular cloud has now turned into stars, so we expect the rate of star formation to decline in the next few million years."

With the Tarantula, it's almost as if astronomers have stumbled on their own Rosetta Stone, and have started using it as a key to understanding the mysteries of star and galaxy formation.

When the show eventually ends, every astronomer in the house will say it had a great run.

The Tarantula Nebula has transfixed Contributing Editor **Richard Talcott** *since he first started to explore the universe. His latest book is* Space Junk *(Ziga Media, 2019).*

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

This starlit shot of the Athabasca River in Alberta, Canada, features the constellations Aquarius, Piscis Austrinus, and Cetus. This same region of the sky hosts Neptune this month. ALAN DYER

SEPTEMBER 2021

Neptune's turn at opposition

Six major planets are in view before midnight during September, offering a full range of binocular and telescopic sights. Mercury and Venus hug the western horizon soon after sunset, while Jupiter and Saturn provide a dazzling spectacle in the southeast. Both planets are well placed all evening. Uranus and Neptune are best viewed in binoculars or a telescope.

Elusive **Mercury** tries to hide from us, but dedicated observers should successfully find it in evening twilight. Mercury is not particularly well placed for Northern Hemisphere observers as it reaches its greatest elongation east of the Sun (27°) Sept. 13. This is because the ecliptic forms a very shallow angle to the horizon. The planet shines at magnitude 0.2 on the 13th and then slowly dims, reaching 0.7 by the 27th.

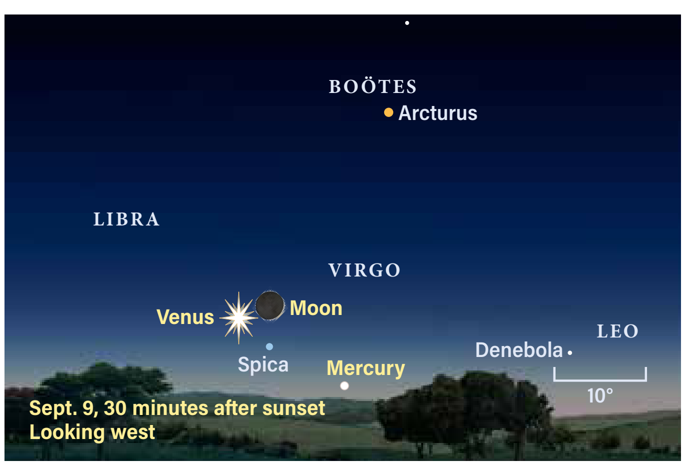
Look for Mercury 30 minutes after local sunset. On the 1st, it stands 3.5° high in the western sky. By Sept. 7, Mercury stands slightly south of due west. A one-day-old Moon lies closer to due west but sets within 50 minutes of the Sun, so a clear western horizon and transparent skies are needed to see it. Try the more favorable evening of the 8th, when a fatter crescent Moon stands 5° nearly due north of Mercury 30 minutes after sunset. Look for the Moon in binoculars, then scan downward to find Mercury. The planet outshines Spica (magnitude 1), which appears between Venus, the brightest planet in the sky, and Mercury.

By Sept. 9, the waxing crescent Moon stands just under 4° north of Venus, a stunning pair in the celestial blue of twilight. Look with binoculars about 5° directly below the Moon to find Spica. Use the Moon and Venus to aid in finding Mercury, still close to the horizon and 13° to the lower right of the Moon. Thirty minutes after sunset, Mercury is less than 3.5° high.

Mercury and Spica stand 1.5° apart on Sept. 21, with Mercury about a half magnitude brighter than its stellar companion. Begin searching shortly after sunset, because you know by now that Mercury sets quickly. After this date, the planet dips even lower, becoming harder to find.

Venus is easier to spot, even though it's low in the sky. This is due to its brilliance: It shines at magnitude –4. Early in the month, Venus sets half an hour after Mercury and stands

Swinging low



Observers able to get out right after sunset and with a clear view of the western horizon can catch Mercury below Venus and the Moon Sept. 9.
ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

NEPTUNE reaches opposition Sept. 14 in Aquarius, when it will sit 4° northeast of 4th-magnitude Phi (ϕ) Aquarii.

11° high in the southwest 30 minutes after sunset. Spy Venus through binoculars on Sept. 4; as the sky darkens, see if you can spot Spica less than 2° due south of the dazzling planet.

As we've mentioned, the Moon and Venus stand close on the 9th, while Venus coasts across the backdrop of southern Virgo. By the end of September, Venus sets nearly two hours after the Sun, although it hugs the horizon all month. With a telescope, you can watch the planet inflate from 15" to 19" in apparent diameter and change from 73 percent to 62 percent lit throughout the month.

Across the sky, two bright planets are well placed in the southeast for viewing. Saturn is first, shining at magnitude 0.3 in western Capricornus. It stands 14° high at sunset. Jupiter follows Saturn across the sky, located 18° farther east in Capricornus. At magnitude –2.9, the giant planet clearly outshines Saturn. Both planets are past opposition, which they reached in August, and are best viewed from 10 P.M. local time onward, when they stand high in the southern sky.

Saturn is a stunning object in any telescope, revealing its magnificent ring system encircling the 18"-wide planetary disk. The rings are tilted 19° to our line of sight, with their northern face on view. Over the next few years, the rings will become narrower, revealing more of the planet's southern hemisphere. The outer dusky Ring A is separated from the brighter Ring B by the Cassini division. If you can easily make out the division, your seeing conditions are good. The planet shines with a yellowish hue and rarely reveals significant features unless a storm erupts, visible as an obvious white spot.

Titan is Saturn's brightest moon, shining at magnitude 8.5. It orbits Saturn every couple of weeks and appears north of the planet Sept. 3 and 19, and south of the planet Sept. 11 and 27.

— Continued on page 38

RISING MOON | Snaking across the Sea of Serenity

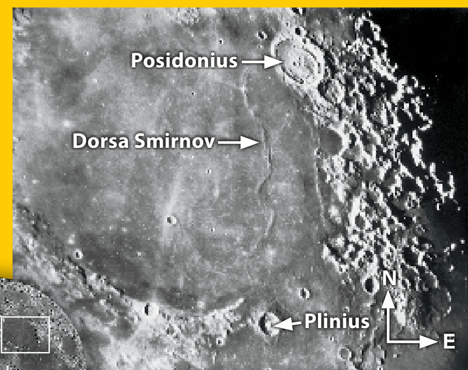
ONE OF THE MOST STRIKING SIGHTS on Mare Serenitatis is the wrinkle ridge Dorsa Smirnov, but the time must be right. When the Sun is low in the lunar sky, the modestly lifted terrain casts shadows across the hardened plains of lava. The prominently paired dark and sunlit faces disappear under a higher Sun.

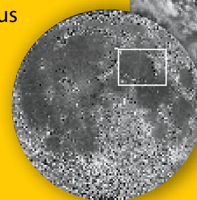
Since most amateurs are evening observers, we normally focus on features just after lunar sunrise, when the Moon is waxing from crescent to Full. Thankfully, the Harvest Moon effect allows us to observe the waning gibbous Moon before midnight. On Sept. 24th and 25th, the Sun begins to set over the Sea of Serenity in what some call reverse lighting. Classic lighting of the Serpentine ridge occurs during the Moon's evening crescent phase, on the 11th of this month and next.

Also called the Serpentine Ridge, Dorsa Smirnov's 200-mile-long complex of wrinkles formed when the regions just under the plains of lava slowly pushed into each other, causing the surface to buckle gently upward. The shapes can remind us of the delicate strands of the Veil Nebula, although the source of those compression forces was a supernova explosion, unlike the much weaker tectonic activity responsible for Luna's features.

Don't miss the fantastic crater Posidonius just to the northeast — it's a joy getting lost in the wonderful detail here. For starters, there are small craters, bumps, rilles, and a second wall. Farther south, the trio of Theophilus, Cyrillus, and Catharina are simply fantastic.

Dorsa Smirnov





Also called the Serpentine Ridge, Dorsa Smirnov winds 200 miles across the Sea of Serenity. *CONSOLIDATED LUNAR ATLAS*/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Catch the false dawn

Dusty curtain

The autumn appearance of the zodiacal light occurs before sunrise, earning it the nickname of false dawn. WILLI WINZIG

AFTER THE FLURRY of major showers in August, meteor rates die down significantly in September. The sporadic or background rate of meteors reaches an average of seven meteors per hour, although the occasional fireball not associated with any shower can illuminate the night sky, so watch out for those events.

Meanwhile, in early September's moonless predawn sky, look out for a delta-shaped brightening stretching from Cancer into Gemini along the steeply inclined ecliptic before the onset of twilight. It's the zodiacal light, best observed from very dark locations far from any streetlights. The glow is from trillions of meteoritic dust particles left over from eons of comets cruising through the inner solar system, dumping fine material as the Sun heats their surface.

STAR DOME

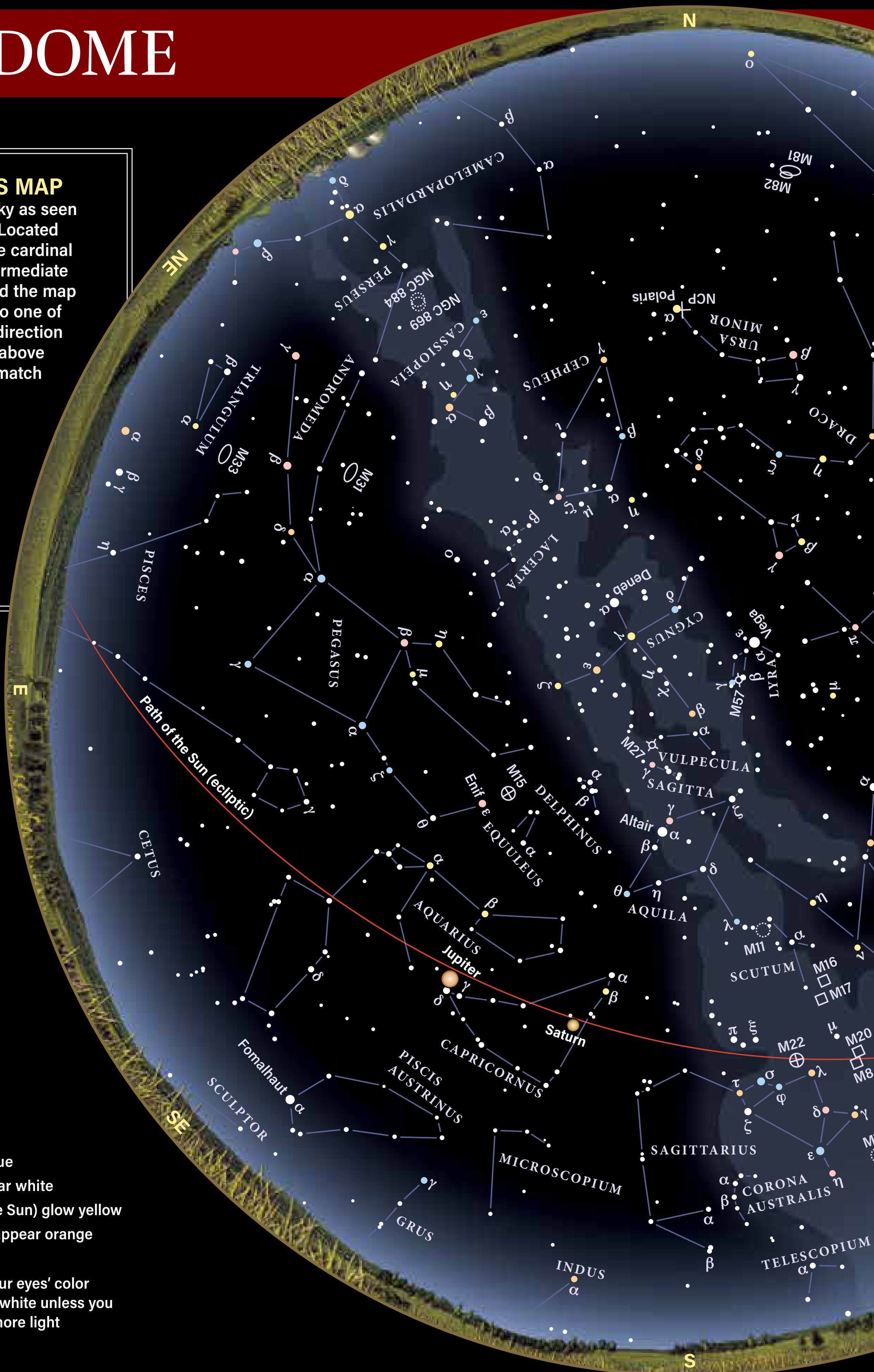
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. September 1
9 P.M. September 15
8 P.M. September 30

Planets are shown at midmonth



MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

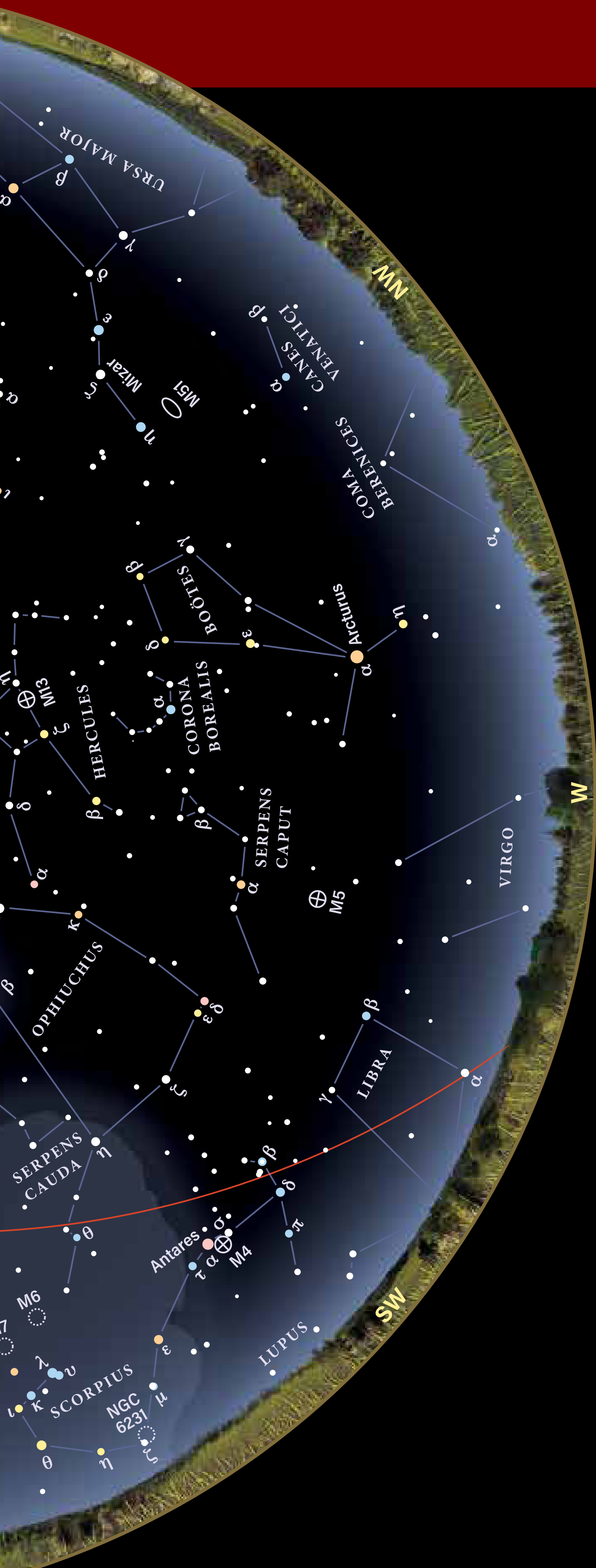
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



SEPTEMBER 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

5 Venus passes 1.7° north of Spica, 2 A.M. EDT

6 New Moon occurs at 8:52 P.M. EDT

8 The Moon passes 7° north of Mercury, 4 P.M. EDT

9 The Moon passes 4° north of Venus, 10 P.M. EDT

10 Asteroid Pallas is at opposition, 10 P.M. EDT

11 The Moon is at perigee (228,951 miles from Earth), 6:03 A.M. EDT

13 First Quarter Moon occurs at 4:39 P.M. EDT

Mercury is at greatest eastern elongation (27°), midnight EDT

14 Neptune is at opposition, 5 A.M. EDT

16 The Moon passes 4° south of Saturn, 11 P.M. EDT

18 The Moon passes 4° south of Jupiter, 3 A.M. EDT

20 The Moon passes 4° south of Neptune, 5 A.M. EDT

Full Moon occurs at 7:55 P.M. EDT

22 Autumnal equinox occurs at 3:21 P.M. EDT

23 Mercury passes 1.7° south of Spica, 8 A.M. EDT

24 The Moon passes 1.3° south of Uranus, noon EDT

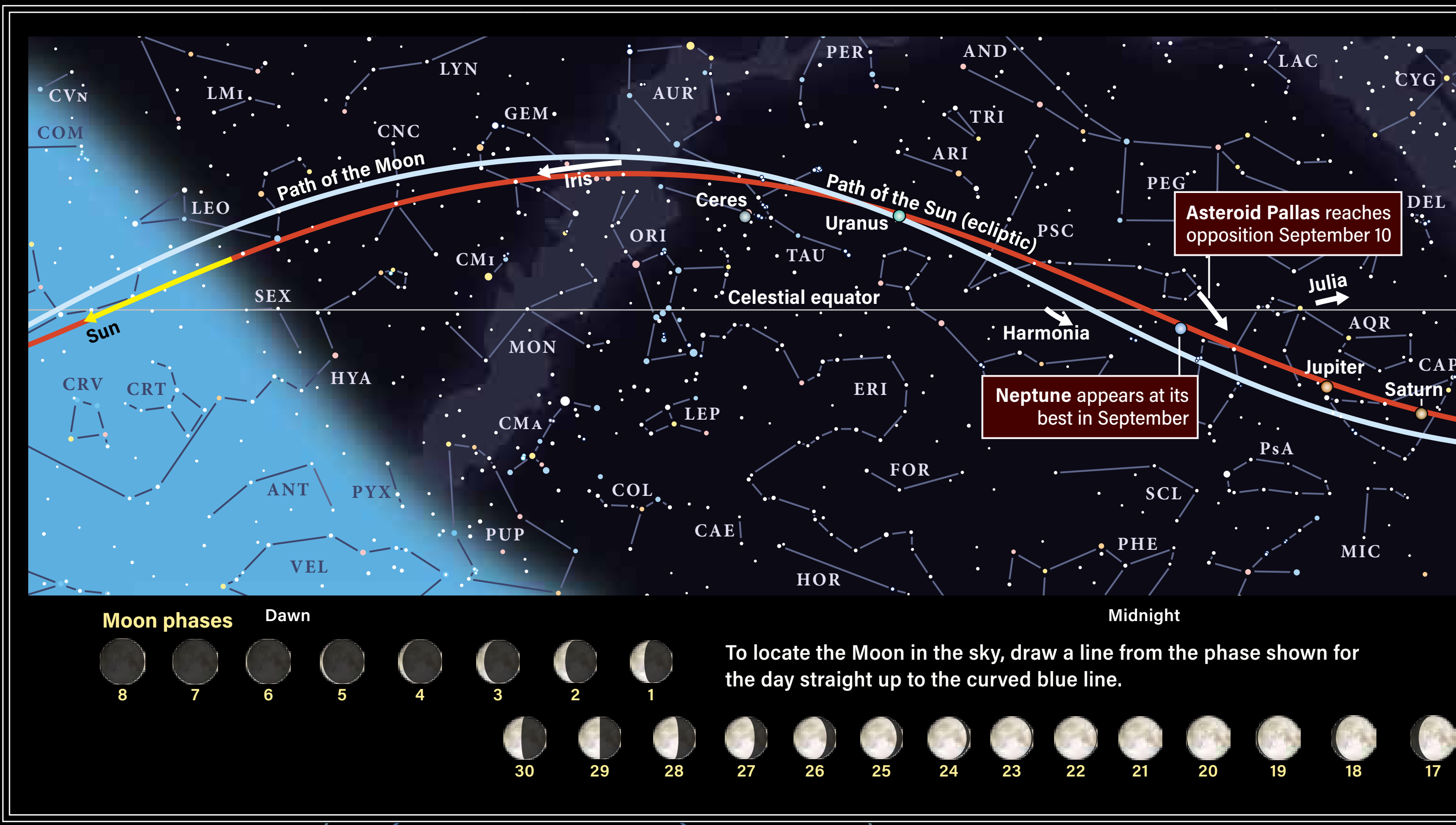
26 The Moon is at apogee (251,432 miles from Earth), 5:44 P.M. EDT

Mercury is stationary, midnight EDT

28 Last Quarter Moon occurs at 9:57 P.M. EDT

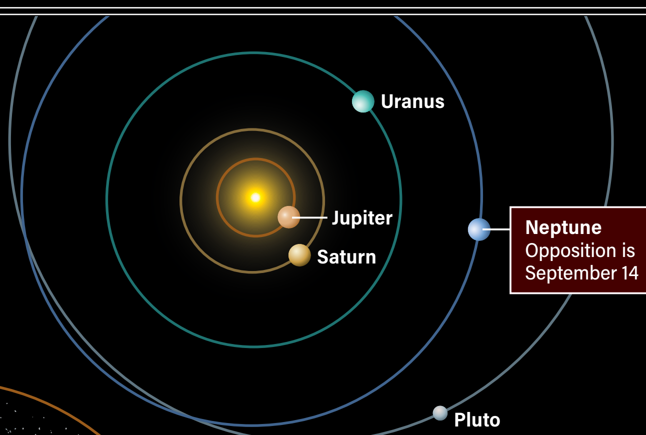
30 Mercury passes 1.7° south of Spica, 11 A.M. EDT

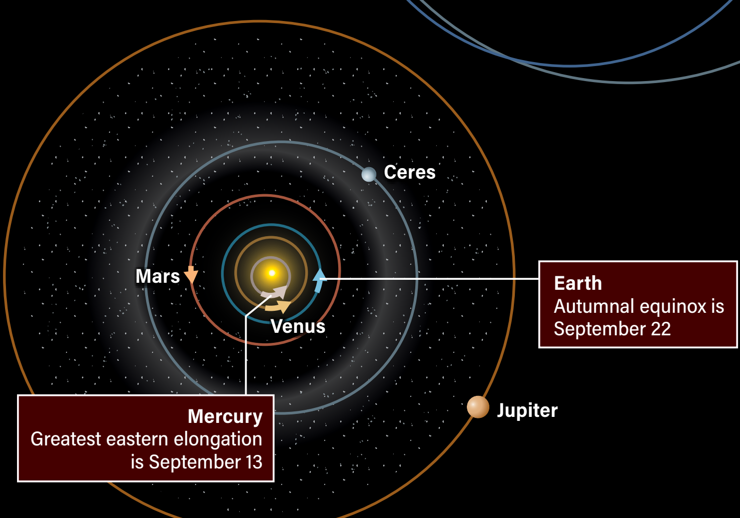
PATHS OF THE PLANETS



THE PLANETS IN THEIR ORBITS

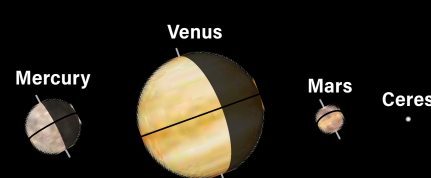
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

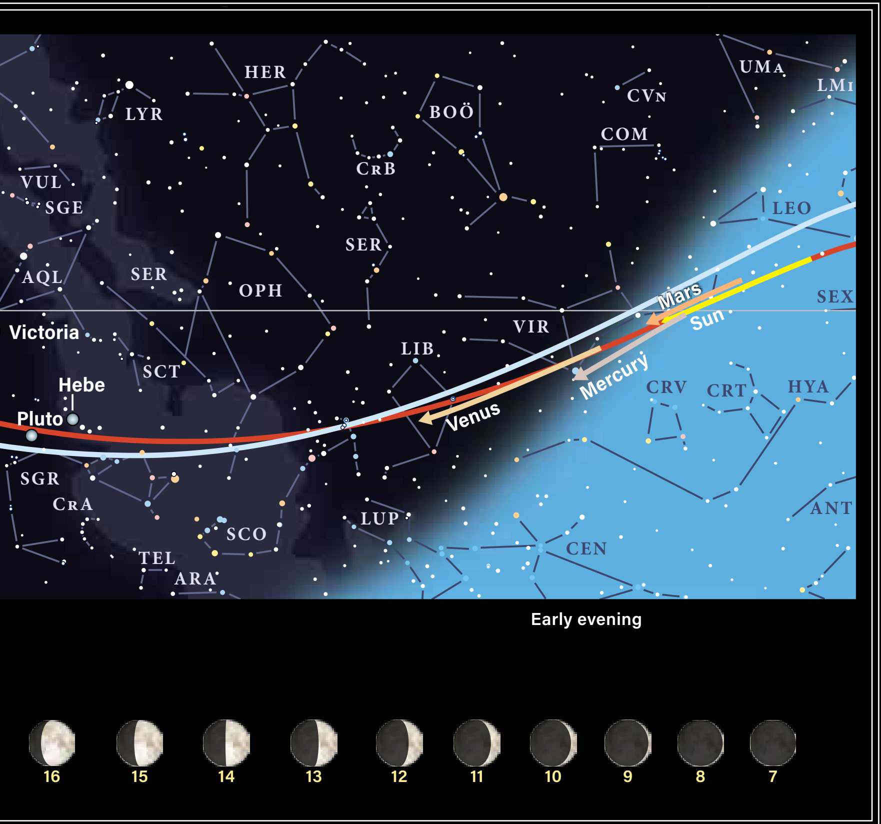
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	Sept. 15	Sept. 15
Magnitude	0.2	–4.1
Angular size	7.1"	16.6"
Illumination	56%	68%
Distance (AU) from Earth	0.950	1.007
Distance (AU) from Sun	0.456	0.728
Right ascension (2000.0)	13h04.8m	14h07.3m
Declination (2000.0)	–9°51'	–14°03'

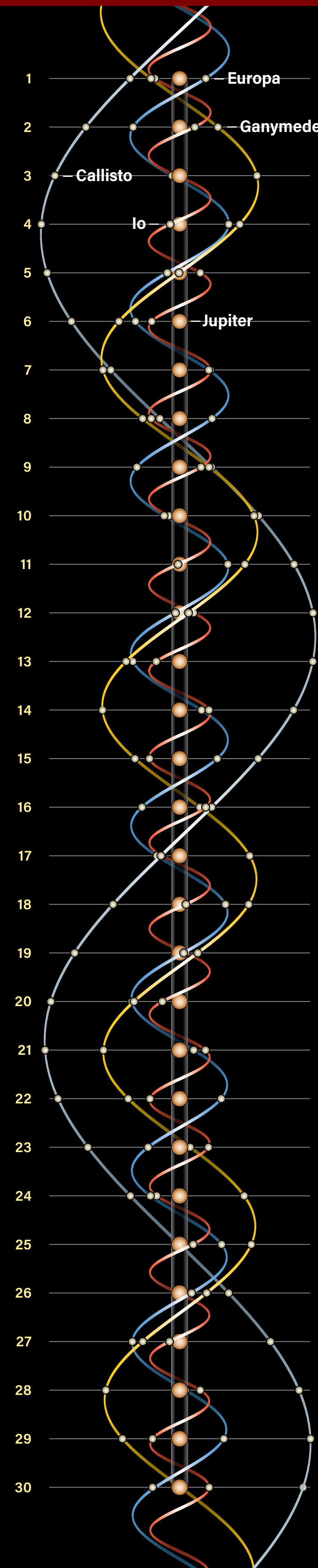
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

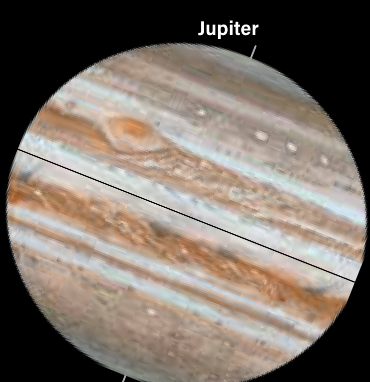
SEPTEMBER 2021

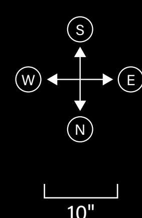


JUPITER'S MOONS

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.

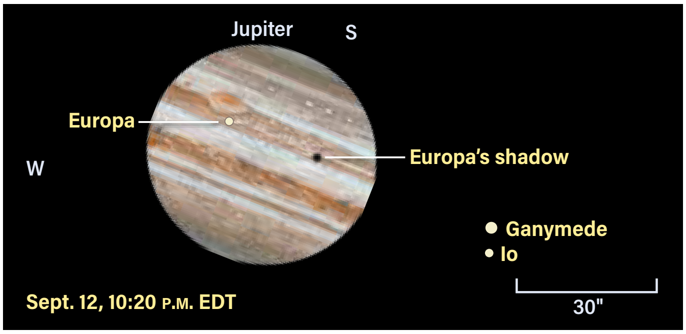






MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15
1.7	8.6	–2.8	0.3	5.7	7.7	15.1
3.6"	0.5"	48.0"	18.1"	3.7"	2.4"	0.1"
100%	97%	100%	100%	100%	100%	100%
2.637	2.420	4.110	9.205	19.104	28.917	33.818
1.646	2.805	5.018	9.942	19.738	29.922	34.362
12h00.2m	4h37.7m	21h46.1m	20h39.0m	2h47.6m	23h30.5m	19h45.3m
0°52'	15°41'	–14°43'	–19°17'	15°42'	–4°28'	–22°54'

Close pass



Io and Ganymede pass within 6" of each other Sept. 12, as Europa and its shadow are traversing Jupiter's disk. Callisto lies farther east.

Rarely, a field star of similar magnitude enters the field of view, as on Sept. 12 and 13. On the 12th, the two are near each other southwest of Saturn; on the 13th, Titan remains southwest and the slightly brighter field star is southeast of the planet at a similar distance.

Magnitude 12 Enceladus tours around Saturn a few arcseconds from the bright edge of the rings, which make it hard to spot. A collection of brighter 10th-magnitude moons — Tethys, Dione, and Rhea — orbit a bit farther out with periods ranging from two to five days.

Iapetus is at inferior conjunction with Saturn on the last day of August. As September opens, it lies 1.5' southwest of the planet and glows near 11th magnitude. The moon brightens throughout the month, reaching a peak around magnitude 10 at western elongation Sept. 20, when it stands 9' due west of Saturn. The change occurs as its brighter trailing hemisphere becomes more visible from Earth at western elongation.

Jupiter's retrograde loop carries it deeper into western Capricornus, passing 1.5° north of 3rd-magnitude Deneb Algedi on Sept. 12. The planet is due south at roughly 35° altitude at local midnight (depending on your local latitude). This is a few degrees better than last fall. Higher elevation means less interference from our own turbulent atmosphere, producing a brighter planet for those capturing video.

Observing Jupiter is always a thrill. The planet exhibits two thick dark equatorial belts on a broad 48"-wide disk. Brighter zones to either side of these dark belts are replete with both subtle and not-so-subtle cloud features, which the planet carries along with its rapid rotation period of less than 10 hours. Occasionally, the Great Red Spot makes an appearance. Such features move visibly within 10 minutes, making the planet a hit with all observers.

Jupiter is joined by four bright moons: Io, Europa, Ganymede, and Callisto. Collectively, these Galilean moons, so called because Galileo first reported them, change relative positions as they orbit with periods ranging from less than two days to 14 days.

The moons regularly undergo eclipses, transits, and shadow transits, sometimes two at a time. On Sept. 5, East Coast observers see Europa and its shadow crossing the planet's face just as Ganymede begins a transit at 8:59 P.M. EDT. Ganymede begins at the eastern limb, while Europa leaves the western limb one minute later. Europa's shadow leaves Jupiter 51 minutes after that, at 9:51 P.M. EDT. As darkness falls

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (west)
Venus (west)
Jupiter (southeast)
Saturn (southeast)
Neptune (east)

MIDNIGHT
Jupiter (south)
Saturn (southwest)
Uranus (east)
Neptune (south)

MORNING SKY
Uranus (southwest)
Neptune (west)

COMET SEARCH | Rubbernecking encouraged

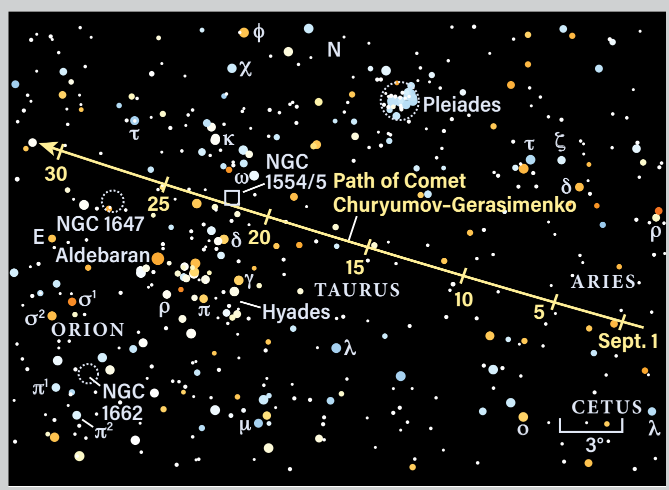
SEVEN YEARS AGO, the Rosetta spacecraft surveyed Comet 67P/Churyumov–Gerasimenko by dropping the Philae probe onto the surface, later finishing the adventure with its own soft landing.

The comet rises before midnight along with the Pleiades in the northeast, but you'll want to wait until the wee hours of the morning for it to get above the thickest part of our atmosphere. Our two-week Moon-free window closes midmonth. Glowing feebly at magnitude 10 to 11, Churyumov–Gerasimenko requires an 8- to 10-inch scope from a dark site.

At high power, the rubber duck-shaped nucleus of a couple of miles across will be cloaked in a literal flurry of ice and dust — there's even a movie of that! The east (Sun-facing) flank is well defined, the solar wind pushing the dust into a diffuse, stubby fan to the west. Prep your scope and eyepieces to ward off the formation of dew, which is common in September.

Identified in 1969, Churyumov–Gerasimenko is a modestly recent discovery. It returns every 6.4 years to a spot just inside Mars' orbit before looping out to Jupiter's vicinity. In the distant future, giant Jove's gravity will fling Churyumov–Gerasimenko off on a new adventure.

Comet 67P/Churyumov–Gerasimenko



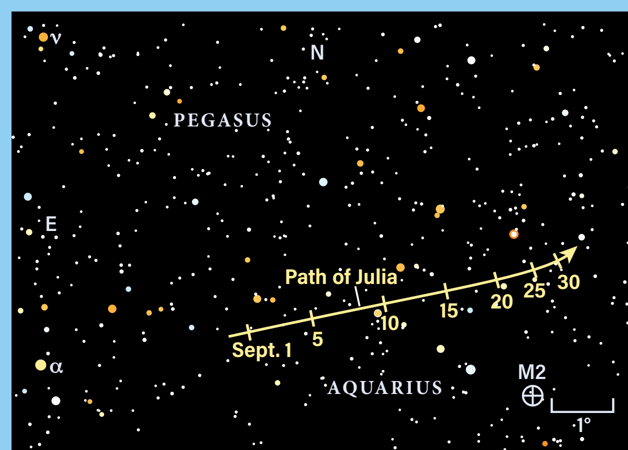
The rubber duck-shaped Comet Churyumov–Gerasimenko travels through crowded Taurus this month. You'll need a larger telescope and a dark observing site to spot its glow.

LOCATING ASTEROIDS | Backward motion

SPEEDIER EARTH overtakes the main-belt asteroid 89 Julia, causing it to go retrograde, or appear to move westward, through the constellation Aquarius. You'll find it straight south of Pegasus' nose star, magnitude 2.4 Enif (Epsilon [ε] Pegasi).

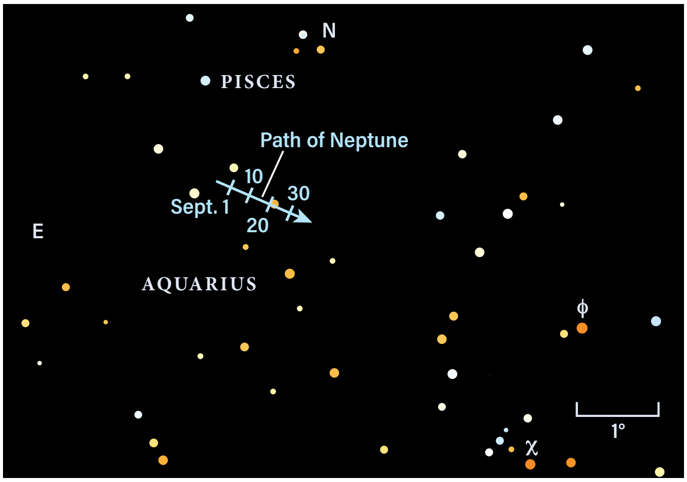
The bright globular cluster M2, visible in a 4-inch scope from the suburbs as an unresolved cotton ball, serves as a jumping-off point to magnitude 9 Julia. Avoid the nights leading up to the Full Moon, when there is extra light in the sky. Hiding in plain sight, Julia's gradual shift from night to night gives it away. Keep a sketch of the three or four brightest stars in the field where the chart indicates, and you'll pick out the one that moved. That's how Édouard Stephan found it in 1866, by meticulously comparing the real sky against charts. Later, through recording the variations in brightness as Julia spins, astronomers deduced the asteroid is a 90-mile-wide crumpled-looking ball.

Under your nose



Asteroid Julia is traveling through Aquarius in a region south of Pegasus' nose star, Enif.

Neptune's slow slide



Neptune reaches opposition this month. It spends September in Aquarius, near a triangle of three 6th-magnitude field stars.

across the midwestern U.S., Ganymede's transit is well underway. At 10:45 P.M. EDT, Ganymede's huge shadow falls on the jovian cloud tops.

Illustrating the wonderful synchronous orbital periods of these two moons, this event repeats itself on Sept. 12/13. Europa begins a transit across Jupiter at 8:26 P.M. EDT. Its shadow transit starts 9:37 P.M. EDT. Look east of Jupiter to find Io and Ganymede moving in opposite directions. They are closest — less than 6" apart — at 10:20 P.M. EDT. Ganymede heads to a 12:20 A.M. EDT (on Sept. 13) transit, followed by its shadow at 2:47 A.M. EDT. The huge, jet-black spot is clearly visible in any telescope.

There are many other transits and occultations of individual moons with Jupiter. On Sept. 3, Io and Europa disappear behind Jupiter's western limb 72 minutes apart, with Io vanishing at 10:30 P.M. EDT. A good place to check for other events is the Royal Astronomical Society of Canada's 2021 *Observer's Handbook*.

Neptune reaches opposition Sept. 14 and remains visible all night. At its distance of nearly 2.7 billion miles, Neptune musters a span of 2" and a magnitude of 7.7, rendering it visible in binoculars. High magnification in a telescope and steady seeing is needed to see its bluish-green disk. Neptune stands 6° north of the Sept. 19 Full Moon.

You can track Neptune's motion against the background of stars in eastern Aquarius using binoculars. The planet is located nearly 5° east of 4th-magnitude Phi (ϕ) Aquarii, and the gap reduces to less than 4° as the month progresses. Look for a triangle of 6th-magnitude field stars roughly 6.5° south of the Circlet in Pisces — Neptune is near this grouping all month. In fact, on Sept. 23, the planet makes a particularly close pass (1.5') of the westernmost star in the triangle. You'll need a telescope to see this close appulse.

Uranus rises around 10 P.M. local time on Sept. 1, and two hours earlier by Sept. 30. At midmonth, it is 20° high in the eastern sky by 11 P.M. local time. The magnitude 5.7 planet is an easy target for binoculars, although it remains challenging to spot in a dim part of southern Aries. A telescope shows a delightful pale bluish disk spanning 4".

To find Uranus, begin by searching for a triangle of stars formed by Omicron (ο), Sigma (σ), and Pi (π) Arietis. This trio of 5th-magnitude stars stands 6° due north of Mu (μ) Ceti. Uranus starts the month in the lower middle of this triangle, equidistant from Omicron and Sigma. It then wanders westward toward Omicron as the month progresses. By Sept. 30, Uranus stands within 25' of this star. Note the gibbous Moon in the vicinity Sept. 24, with Uranus 5.5° northeast of our natural satellite shortly after rising.

Mars is too close to the Sun to observe it during September. The Red Planet returns to the morning sky in December.

Sept. 22 marks the autumnal equinox (3:21 P.M. EDT), the time of year when the Sun appears on the celestial equator, moving southward.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

Discover the STRANGEST GALAXIES in the sky

Crashing, colliding, and tangoing, these peculiar galaxies reveal the grand evolution of the cosmos. BY ALAN GOLDSTEIN

M82 is a nearby galaxy forming stars 10 times faster than the Milky Way. This prodigious rate of production is due to gravitational interactions with its neighboring galaxy, M81. PATRICK WINKLER

Forty years ago, I penned my first of many articles for *Astronomy*. It ran in the February 1981 issue as "Observing Peculiar Galaxies."

The term *peculiar galaxies* refers to a class of galaxies whose distorted shapes resemble neither classical spiral galaxies nor amorphous elliptical galaxies — and at the time, they were still mysterious. Just 16 years earlier, Halton Arp had published his *Atlas of Peculiar Galaxies*, a product of his documentation of objects while examining the Palomar Sky Survey. It contained a sampling of some the most unusual galaxies whose warped structures defied explanation.

After the passage of four decades, our understanding of what makes such galaxies peculiar has improved — thanks to the Hubble Space Telescope, giant new telescopes with adaptive optics, and more powerful computers that can model the gravitational dances of interacting galaxies.

Eyepiece improvements and larger telescopes have enabled the humble amateur astronomer to see details that were impossible to make out decades ago. Digital imaging technology allows amateurs to take professional-quality images that were unattainable with film. But at the same time, urban areas have seen tremendous growth, making it necessary to travel farther to get under truly dark skies. After all these changes, it's only fair to revisit that topic with a new eye.

What makes a galaxy peculiar?

With the great diversity among "normal" galaxies, one may wonder if every galaxy has its own peculiarities. To an extent, there may be some truth to that statement. Edwin Hubble created the basis of the classification system that is used today nearly 100 years ago.

The "tuning fork diagram" contains spirals — normal and barred — in the two prongs, with ellipticals galaxies in the handle. Irregular galaxies are outside. Over time, the structure has been tweaked with two additional classifications. Lenticulars are spirals without active star formation that share characteristics with ellipticals. And we now use the term *transitional barred spirals* to refer to the so-called "SAB-type" in Gérard de Vaucouleurs' galaxy classification system that he developed in the late 1950s.

Galaxies tend to occur in clusters, just like stars. But unlike stars, the sheer mass of galaxies encourages them to interact and even collide. A galaxy's stars, dust, and hydrogen gas are all influenced by an interaction. Even a passage separated by a hundred thousand light-years provides gravitational tugs potent enough to distort galactic structure. This all happens in extreme slow motion: The passage of galaxies relative to one another takes hundreds of millions of years or longer.

The gravitational tango of NGC 4485 and NGC 4490 twirling around each other has created a stream of stars that connects the two. DAN CROWSON

NGC 4027's distinctive shape is likely due to an interaction with an unseen companion galaxy. It's located in the Crow, less than half a degree south of the famous Antennae Galaxies. ESO

As you might expect, the No. 1 cause of peculiarities is collision. An estimated 5 percent of galaxies in the visible universe are interacting. And if we had infrared vision, that number would rise to 25 percent; galaxies that emit mostly infrared light seem to interact at a higher rate. Other causes include bursts of star formation (related to collisions or interactions with intergalactic hydrogen clouds) and exploding cores (due to massive black holes). Some have anomalously large clouds of dust or glowing ionized hydrogen gas (HII regions). A small percentage are still mysterious. Given time and technology, these will become understood.

What can you see?

The good news for amateur observers is that plenty of peculiar galaxies are bright enough to be seen in 4- to 10-inch telescopes. Several can even be picked up in binoculars.

Observing detail, however, is another matter. If you have not dabbled in peculiar galaxies before, it is better to simply find these targets and not worry if you don't see a peculiar feature.

To bring out the most detail possible, nothing beats a large aperture and dark, unpolluted skies. Another strategy to eke out shreds of detail is to avert your vision slightly to one side of the object, relying on your retina's more light-sensitive rod cells. Perhaps they will reveal a bit of asymmetry, a faint companion, a bright patch or arm, or a shadowy dark nebula.

Some observers study a photo or two before looking at their target. Bright stars in the field may help you locate the most conspicuous aspect of the galaxy's peculiarity. Keep in mind that photos may be reversed from what you see in the eyepiece.

I enjoy every aspect of observing peculiars, from checking off another "faint fuzzy" to seeing detail. If you don't go in expecting to see many details, you won't be disappointed — or, from a more optimistic perspective, you may be pleasantly surprised!

Taking up the challenge

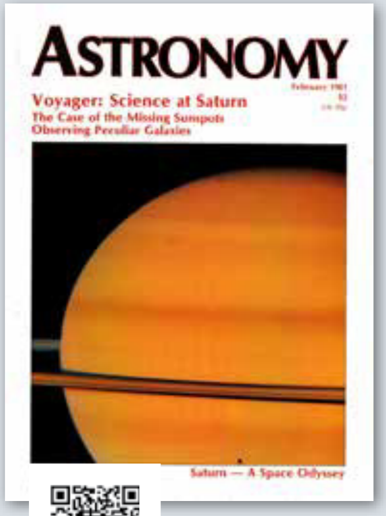
My 1981 article featured 12 of my favorite peculiar galaxies. Since then, I've observed many other peculiar galaxies with larger optics. Here are 12 of my *new* favorites:

NGC 1228, **NGC 1229**, **NGC 1230**, and **IC 1892** make up a chain of galaxies in Eridanus. These four are also known by their designation in Arp's atlas, Arp 332. They are a faint quartet, in the 13th- to 14th-magnitude range, a challenge for a 10-inch scope. Why do galaxies line up? Perhaps it's random chance, or maybe they evolved together in their own "local group." NGC 1229 is a Seyfert-type

LOOKING BACK ON PECULIARS

The author's first story in *Astronomy* appeared in February 1981, featuring 12 of his favorite peculiars.

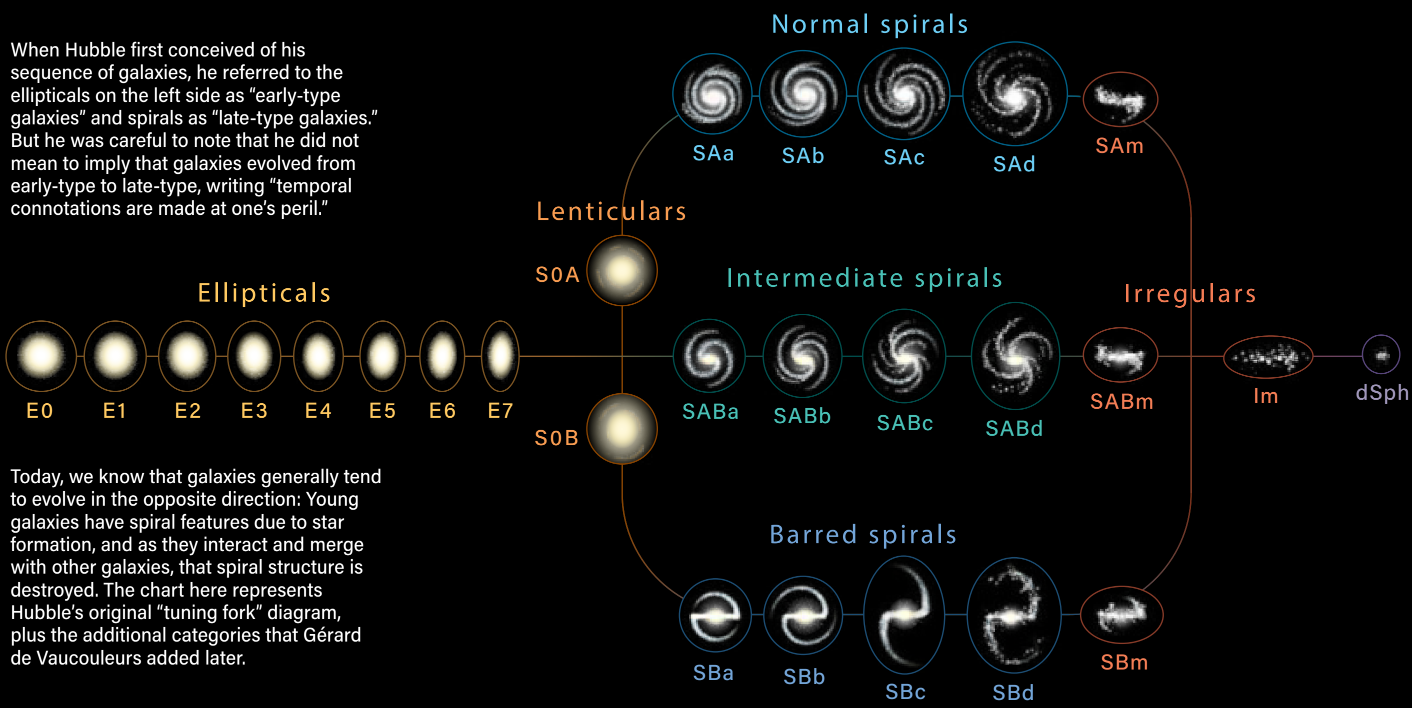
NGC 520	Colliding galaxies
NGC 772	Interacting with smaller companion
NGC 1097	Interacting with smaller companion; features jets
NGC 1961	Warped and extended with no known companion
NGC 3718/29	NGC 3718 is warped with dark lanes; its companion NGC 3729 is 150,000 light-years from it
NGC 4038/9	Two colliding galaxies
NGC 4088	Interacting with odd arm structure
NGC 4861	Irregular, dwarf galaxy
NGC 5128	Elliptical galaxy collided with a spiral
NGC 5195	Irregular galaxy
M101	Spiral with asymmetrical arms
NGC 7727	Two galaxies combined



Scan the QR code to read the story online.

GALACTIC MENAGERIE

When Hubble first conceived of his sequence of galaxies, he referred to the ellipticals on the left side as "early-type galaxies" and spirals as "late-type galaxies." But he was careful to note that he did not mean to imply that galaxies evolved from early-type to late-type, writing "temporal connotations are made at one's peril."



Today, we know that galaxies generally tend to evolve in the opposite direction: Young galaxies have spiral features due to star formation, and as they interact and merge with other galaxies, that spiral structure is destroyed. The chart here represents Hubble's original "tuning fork" diagram, plus the additional categories that Gérard de Vaucouleurs added later.

galaxy — one with an active, energetic nucleus due to its central, supermassive black hole gorging on material.

NGC 2207 and **IC 2163** are a pair of spirals in Canis Major. Many observers are aware of this constellation's numerous star clusters like M41. But the Big Dog also contains a number of galaxies, including this pair in the early stages of colliding. The smaller (and more distant) of the two, IC 2163, looks comma-shaped, with arms stretched by tidal forces.

M82 (NGC 3034) in Ursa Major is a starburst galaxy, so called because it forms stars at a much greater rate than most galaxies. Called the Cigar Galaxy because it is long and narrow with rounded ends, it's easy to see with small scopes. This Cuban is shrouded in smoky dark nebulae that can likewise be seen in small telescopes. With larger optics, the detail in the dusty shreds is fun to observe. How much detail can you see?

NGC 3226 and **3227** are nowhere close to being the brightest galaxies in Leo. But I like them because they are a "four-fer": The bright double star Gamma (γ) Leonis lies less than a degree west of the pair (which makes them easy to find). NGC 3226 is an elliptical galaxy. NGC 3227 is a spiral. And NGC 3227 has an active nucleus. In a telescope, they appear as two oval glows with compact nuclei.

NGC 4027 in Corvus is a hook-shaped barred spiral galaxy. Its form is reminiscent of the more famous Antennae Galaxies of NGC 4038/9 (featured in the opening and closing scenes of the 1999 sci-fi comedy *Galaxy Quest*). The asymmetry of what I call the "Fishhook Galaxy" is due to a collision in its distant past that triggered stars to form, brightening one side. It is readily visible in moderate optics. After observing the large number of galaxies from edge-on to face-on, seeing one that is curved is a pleasant surprise.

NGC 4485 and **NGC 4490** are an interacting pair in Canes Venatici that is bright enough to be seen in small optics, and close enough to show detail with more aperture. NGC 4485 was originally thought to be irregular or a weak spiral like the Large Magellanic Cloud. Its asymmetry is due to a grazing collision with the larger galaxy NGC 4490. That clash caused star formation to occur in a trail connecting the two galaxies, now separated by only 24,000 light-years. That's only slightly closer than the Sun's distance to the center of our galaxy.

NGC 4656 and **NGC 4657**, located in Canes Venatici, is a near edge-on spiral that is classified as SB(s)m, like

THE NEW FAVORITES

NGC 1228/29/30 and IC 1892	Galaxy "chain"
NGC 2207 and IC 2163	Slightly distorted interacting spirals
M82 (NGC 3034)	Undergoing starburst (Cigar Galaxy)
NGC 3226/7	Interacting pair; one Seyfert-type
NGC 4027	Asymmetrical barred spiral ("Fishhook Galaxy")
NGC 4485 and NGC 4490	Two distorted interacting spirals of different sizes
NGC 4656/7	Edge-on spiral with dwarf companion on end (Hockey Stick Galaxy)
M64 (NGC 4826)	Anomalous dark lane (Black Eye Galaxy)
M60 (NGC 4649) and NGC 4647	A galactic accident waiting to happen (in the beginning stages of colliding)
NGC 5426/7	Twin Sc spirals touching
NGC 6621/2	Distorted interacting spirals
NGC 6946	Undergoing starburst (Fireworks Galaxy)

M60 is a large elliptical with a supermassive black hole as massive as 4.5 billion Suns; it's flanked by NGC 4647, a smaller, younger spiral. Astronomers think this odd couple is only in the early stages of its relationship — no new star formation can be seen, but observations from the Hubble Space Telescope suggest tidal interactions have just begun. DAN CROWSON

NGC 4656 and NGC 4657 combine to form the Hockey Stick Galaxy (lower left). The edge-on spiral NGC 4631 is located half a degree to the northwest.
TERRY HANCOCK AND TOM MASTERSON

the Large Magellanic Cloud. NGC 4657 forms the clump of HII regions and star clouds. A thin ray with a short curve at one end gives it the moniker "Hockey Stick Galaxy." It bears magnification well. Look for it near NGC 4631 — a larger, brighter edge-on spiral — as this region of the sky is a fun area to explore with a wide-field scope.

M60 (NGC 4649) and **NGC 4647**, in Virgo, are an unusual duo because they have different classifications, masses, and overall luminosities. M60 is a large elliptical, appearing nearly round (between E1 and E2 in Hubble's scheme) and visible in small instruments. NGC 4647 is a face-on intermediate spiral (SABc) with a low surface brightness. This is an example of a pair just beginning to collide.

M64 (NGC 4826) is peculiar in having a large, asymmetric dark nebula that blocks light from one half of its inner spiral disk. This feature was first noted by William Herschel in the 1780s, leading him to coin the name "Black Eye Nebula" for this galaxy. Located in Coma Berenices, M64 is a favorite for small telescope users because its "black eye" is easily observed hugging the central hub. Larger scopes will show the ragged nature of this dust cloud. Lesser known is the fact that although M64 is a type 2 Seyfert galaxy, its bright central emissions do not appear to originate from an active core, but rather from the region just around it. This may be because the core is obscured along our line of sight.

NGC 5426 and **NGC 5427** in Virgo are a pair of near-twin Sc spirals in the early stages of colliding. Also cataloged as Arp 271, they are nearly perpendicular to one another. It would be interesting to see how they appear in a few hundred million years. Visually, this is a faint pair and is best viewed with 8-inch and larger optics. Knowing what you are seeing makes this a fun target.

NGC 6621 and **NGC 6622** in Draco are another interacting pair that is fascinating to observe with large telescopes. Smaller scopes can distinguish the larger NGC 6621, a distorted spiral with a long arm arcing over the galaxy's body. NGC 6622 is a compact barred spiral that has an unobscured nuclear region, while the disk of the galaxy is mostly surrounded by dust and stars from NGC 6621.

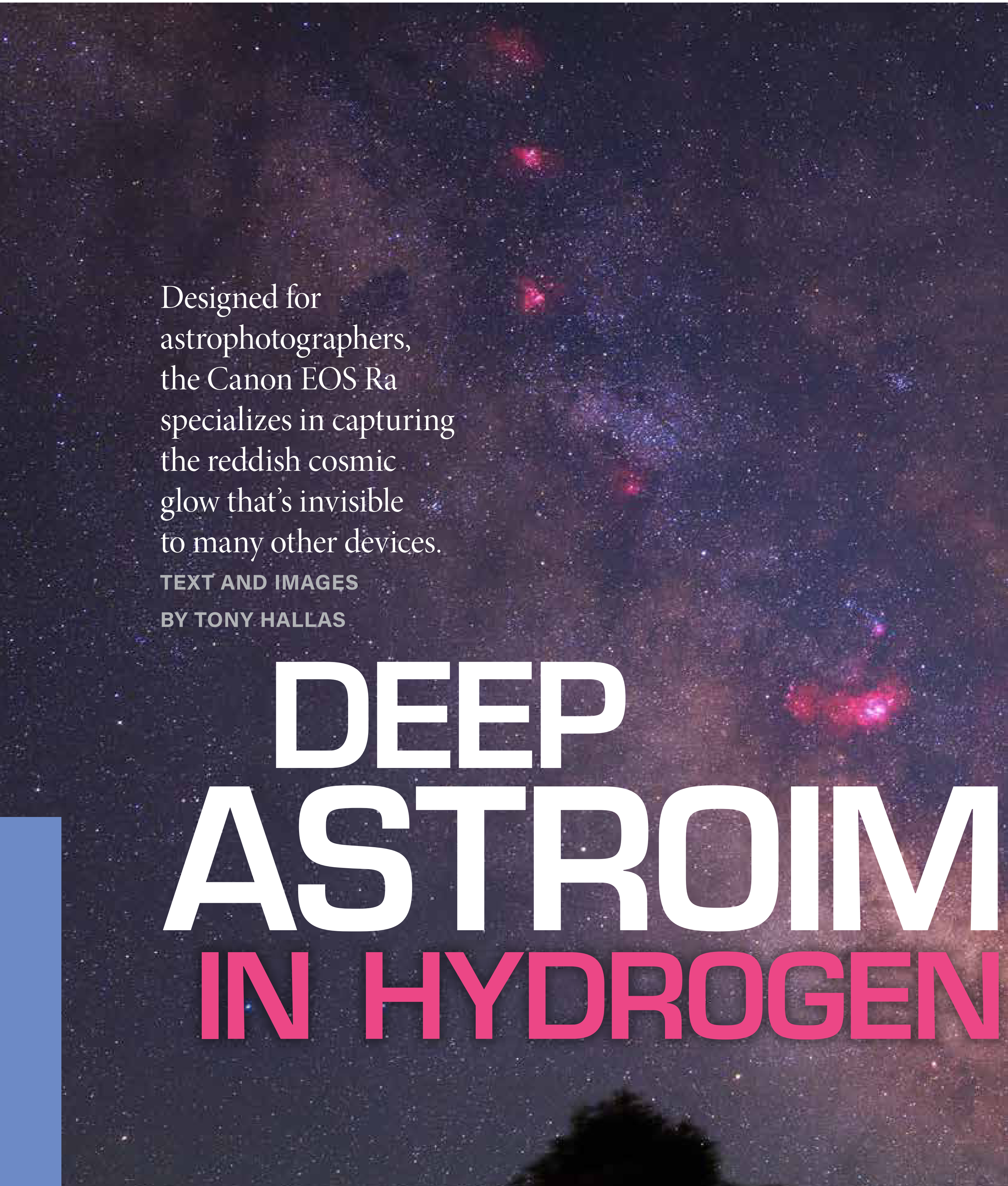
NGC 6946 is not on most lists of peculiar galaxies. This near face-on spiral on the Cepheus-Cygnus border has been nicknamed the Fireworks Galaxy because of its prodigious number of supernovae. While the Milky Way produces an average of one supernova per century, NGC 6946 produces 10 times that rate despite having only one-third as many stars. This Sc-type spiral is also thought to be a starburst galaxy. NGC 6946 is dimmed by interstellar dust from the Milky Way, but is still bright enough

NGC 5426 and NGC 5427 are practically twins: In addition to being nearly the same size, their internal structures are also very similar. DAN CROWSON

for small scopes in dark skies. In large scopes, it shows numerous HII regions and distinct spiral arms.

If you want to stretch the limits of your observing or imaging skills, peculiar galaxies are ideal targets. They are links to the amazing evolution of galaxies — starry halos with the heart of a black hole. Their incredible diversity of form is what makes them worth a look.

Alan Goldstein *has been a contributing author since 1981. He also writes about geology and park interpretation, and his first novel in juvenile fiction has just been published.*



Designed for astrophotographers, the Canon EOS Ra specializes in capturing the reddish cosmic glow that's invisible to many other devices.

TEXT AND IMAGES BY TONY HALLAS

DEEP ASTROIMAGING IN HYDROGEN

AGING
-ALPHA

The Canon EOS Ra follows in the footsteps of the company's 20Da and 60Da: All of these cameras have a special ultraviolet-infrared (UV-IR) rejection filter that allows the transmission of Hydrogen-alpha (Hα) light. As a result, red nebulae that would appear green in normal cameras instead take on a pinkish hue.

The 20Da and the 60Da are older, standard DSLR cameras that utilize mirrors in their viewfinders. The Ra, on the other hand, is a mirrorless camera, so it has a thinner body and doesn't shake as much as cameras with moving mirrors do.

ABOVE: Canon makes a lens adapter for the Ra that includes a slot for inserting filters. There is not currently a set of *narrowband* filters designed for this slot, but the author was able to MacGyver a solution by attaching a string and Velcro to his Astronomik Hydrogen-alpha (Hα) filter.

LEFT: The Milky Way stretches across the sky above the author's home in California in this image taken with the Canon EOS Ra. Although the Ra is already sensitive to Hα light (pink), additional Hα data was captured with a filter and added to the "regular" shot.

Comet NEOWISE (C/2020 F3) is framed by the treeline at the author's home in Foresthill, California, in this image taken with a Canon Ra in the summer of 2020. Processing was carried out in Adobe Camera Raw to help bring out the comet's faint ion tail. Stars were reduced in size and a high-pass filter was applied to make the comet really pop.

One of the most striking features of the Canon Ra is its vari-angle LCD screen, which makes it a easy to view your target no matter where you are pointing the camera. In this case, the target is the Orion Nebula as seen through a 200mm lens.

Previous Canon cameras with mirror-equipped viewfinders relied on Electro-Focus (EF) lenses, but the company also makes a solid adapter that allows you to equip these same EF lenses on their new mirrorless cameras. They even took compatibility one step further, making available another adapter that has a built-in filter slot in its side.

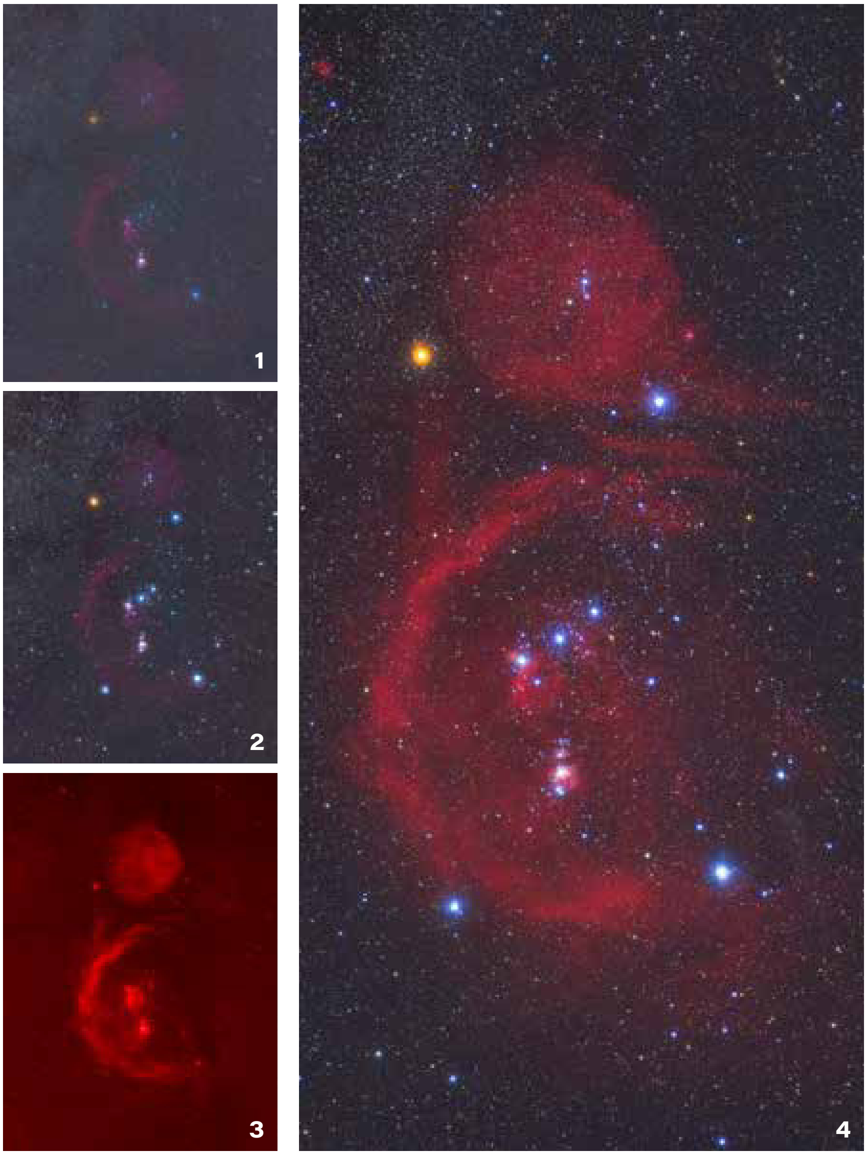
Canon's standard filters are a rotating polarizer filter and a variable neutral density (ND) filter. The idea with these is to simply slide them behind the lens, and one size fits all. But, I wondered, what about putting an astronomy filter in the slot on the adapter? To date, no one makes a dedicated series of narrowband filters meant for that adapter slot. Canon or other filters designed for this slot have a latch mechanism to secure them in place. However, my Astronomik round 50mm Hα narrowband (12 nanometers) filter with metal edging does not. So, using Bondic brand UV-activated glue, I attached a string to this filter so I could retrieve it from the slot. I also added a thin strip of Velcro to the far edge to help stabilize the filter. Once I inserted the filter, I made sure to cover the filter slot with a small piece of material to keep any incidental light from sneaking in.

There are also clip-in filters that you place directly in front of the Ra's sensor before attaching a lens. But utilizing the slotted adapter allows you to change filters without fussing with the camera itself. Plus, you can compose the image with no filter, then insert the filter, focus on a bright star, and start

shooting. One reason I use a 12-nm Hα filter over a 6-nm Hα filter is because it allows me to more easily find a star for focusing, as the 6-nm filter blocks more light. Another reason is the angle of light: If you are using a fast lens, a broader Hα window works better.

As an important note, when you use a glass filter of any kind behind the lens of a camera or telescope, it is going to change the focus! For example, using an Hα filter pushes the focus slightly past infinity, so you need to use a lens that can focus past infinity as well. Many Canon lenses do this, but if you are using a lens that stops right at infinity, it will not work with a Hα filter inserted behind it as described in this article.

Anyway, if you're anything like me, you learn by doing. So let's dive into capturing some beautiful Hα shots of the cosmos with the Canon Ra. Along the way, I'll share the tips and tricks I've learned while frequently using it this past year.



This series summarizes the author's process for creating vivid shots of celestial sights — in this case, Orion. (1) Obtain a set of RGB frames, taking longer exposures at lower ISOs. (2) Take and add a frame using a star blur filter to bring out star colors. (3) Capture a set of frames using an Hα filter, then isolate and enhance that Hα data. (4) Combine these pieces and further process for stunning results.

Capturing the data

The familiar constellation Orion the Hunter is a great winter target for Hα imaging, and it makes for the perfect testing ground. I begin by taking standard RGB exposures. In my experience, a 70mm lens — specifically the Sigma 70mm f/2.8 Art Macro — very nicely frames Orion in the Ra. To track my images, I use a Takahashi EM 200 mount, but any small mount will work as long as it is polar aligned and has a hand paddle for making right ascension and declination corrections.

Long ago, I discovered you get better results in RGB by taking longer exposures at lower ISOs rather than shorter exposures at higher ISOs. So, I typically take four-minute exposures at f/3.3 with an ISO of 800. Between each exposure, I use a hand paddle to nudge the camera a tiny amount, known as dithering, which makes each exposure slightly different from the others. This is something that comes in handy during processing, but more about that later. Usually, I aim to capture 10 RGB exposures.

When I'm done with the RGB frames, I put a star blur filter on the lens (I use a Hoya Soft B filter) and shoot a frame with flared, unfocused stars. This allows me to clearly capture the stars' colors. Without it, modern lenses are so sharp and well corrected that stars often become tiny, near-colorless pinpoints.

Next, I remove the blur filter and insert my 50mm Hα (12 nm) filter

THE FAMILIAR CONSTELLATION ORION THE HUNTER IS A GREAT WINTER TARGET FOR HYDROGEN-ALPHA IMAGING.

AN ALTERNATIVE APPROACH

THERE IS A MORE ADVANCED WAY to add Hα data to your astroimages — one that borrows from CCD imaging. First, while your Hα image is open in Camera Raw, reduce the color saturation to zero. This will make it black and white, but it will also help enhance the Hα details. Combine all the black-and-white Hα exposures in RegiStar, then open that master frame in Photoshop to enhance some more. Specifically, by both sharpening the shot and increasing its contrast, you can make the Hα light really stand out against a dark background.

Now for the CCD trick: Bring the Hα master into Photoshop as a layer on top of the RGB-flare image. Create a Hue/Saturation adjustment layer, then hit the Colorize button. Bring the Color slider to the extreme right (pure red), the Saturation slider to 100 percent, and the Density slider to 50. Create a clipping mask to clip this to the existing Hα layer. Finally, select the now-red Hα layer, change the Blend mode to Lighten, and combine it with your RGB-flare image. This method provides you with more control over the opacity and density of the Hα layer itself.

By first turning your Hα shots into black-and-white views (left), you will ultimately have more control over how intense the Hα data appears in your final composite.

into the adapter slot. Adding this filter changes the focus, so I refocus on a star and increase the ISO to 3200. As you can imagine, the Hα filter blocks a lot of light, so I also must bump up my exposure time accordingly. Each of my Hα exposures last between four and eight minutes, which is why you need good polar alignment. The result is a very red image with pronounced detail. I try to shoot at least five dithered images in Hα.

Processing the images

After I have accumulated all my data frames, it's time to process them. I capture everything in camera RAW format to preserve as much detail as possible. During raw processing, which I do in Adobe Camera Raw, I clean up each exposure and make any adjustments that will benefit the image (which is the topic that would require several articles to thoroughly explain). Once each file looks as good as I can make it, I save it as a 16-bit TIFF.

Remember how we dithered the frames earlier? This is a technique borrowed from CCD processing to increase the signal-to-noise ratio.

After processing the raw images, I upload all the individual image files into RegiStar, which is software that allows you to easily combine and align multiple images into a single composite. I align each filter set of images based on the stars, which appear slightly displaced between each exposure due to our dithering technique. Now, any constant background noise becomes random, and if you average all that noise together, it largely cancels itself out. The result is a master frame for each specific filter that has more and cleaner data than any single shot. I do this for both the RGB frames and the Hα frames.

Next, I use RegiStar to take my three main files — the master RGB frame, the star flare frame, and the master Hα frame — and perfectly align them with each other. (I have detailed my methods for processing in Adobe Camera Raw and Registar on a DVD that is out of print, but I can burn one for you if you are interested. Contact me through www.astrophoto.com.)

Now it's time for Photoshop. I open the master RGB frame and make any additional corrections I think are beneficial, including some star reduction. When it finally looks the way I want it to, I add the star flare frame on top of the RGB frame as a layer and align the two using the Move tool. I change the blend mode to Lighten, which tells Photoshop to take anything from the star flare frame that is lighter (the flares) and add it to the master RGB frame. Like magic, featureless stars in the RGB frame now have both color and proportional size. You can control the degree of this blend by making the flare layer lighter or darker — a neat trick. I save this new RGB-flare master as a Photoshop file with layers before flattening it to simplify the next step.

Here's where the real fun begins: adding the Hα data. Following the same process as before, I add the master Hα frame as a layer on top of the flattened RGB-flare image. I again change the blend mode to Lighten and watch as the RGB-flare image acquires all that beautifully red Hα light. Like before, you can control how much Hα light you blend in by making that layer lighter or darker. You can also use a Burn/Dodge tool to selectively add or subtract Hα data from your final image (which is also possible using layer masks, but the process is a bit more complicated).

When you are satisfied with the final RGB-flare-Hα image, flatten all of the layers and enjoy your new Hα-enhanced view of the cosmos. I hope this helps you get the most out of your fantastic Canon Ra camera!

Tony Hallas *is one of the world's top astroimagers.*

The next 20 *years* of SOLAR ECLIPSES

This list will help you plan the spots where you'll stand beneath the Moon's shadow. **BY MICHAEL E. BAKICH**

This image of the diamond ring and the solar corona was captured Aug. 1, 2008, from Novosibirsk, Russia. BEN COOPER

WITHOUT QUESTION, Earth's most spectacular naturally occurring event is a total solar eclipse. This is only possible because the Sun and Moon take up the same amount of space in our sky, allowing the Moon to perfectly block out the Sun. Experience such a breathtaking moment even once and you'll never forget it.

Astronomers have calculated when eclipses will occur for the next millennium and beyond. So, we know that the next 20 years contain 15 total solar eclipses. Two offer totality in excess of five minutes. Two others have totalities lasting more than four minutes. And two are hybrid eclipses, which exhibit both annular and total phases. But all are worth seeing.

I've listed the eclipses chronologically. Pick those that interest you and start making plans. For detailed information, visit NASA's eclipse website at http://eclipse.gsfc.nasa.gov/eclipse.html. For the best maps of upcoming eclipses, head to www.GreatAmericanEclipse.com.

No matter how much this article and all your planning build up your expectations, a total eclipse will never disappoint.

Dec. 4, 2021

This eclipse is total only in Chile and Argentina; the maximum duration of totality is 2 minutes 10 seconds. The Moon's umbra first touches Chile at the southwestern tip of Isla Mocha, where totality will last 1 minute 19 seconds. There, and for 16 miles (25 kilometers) south along the coast, the best weather in Chile is likely, according to climate statistics.

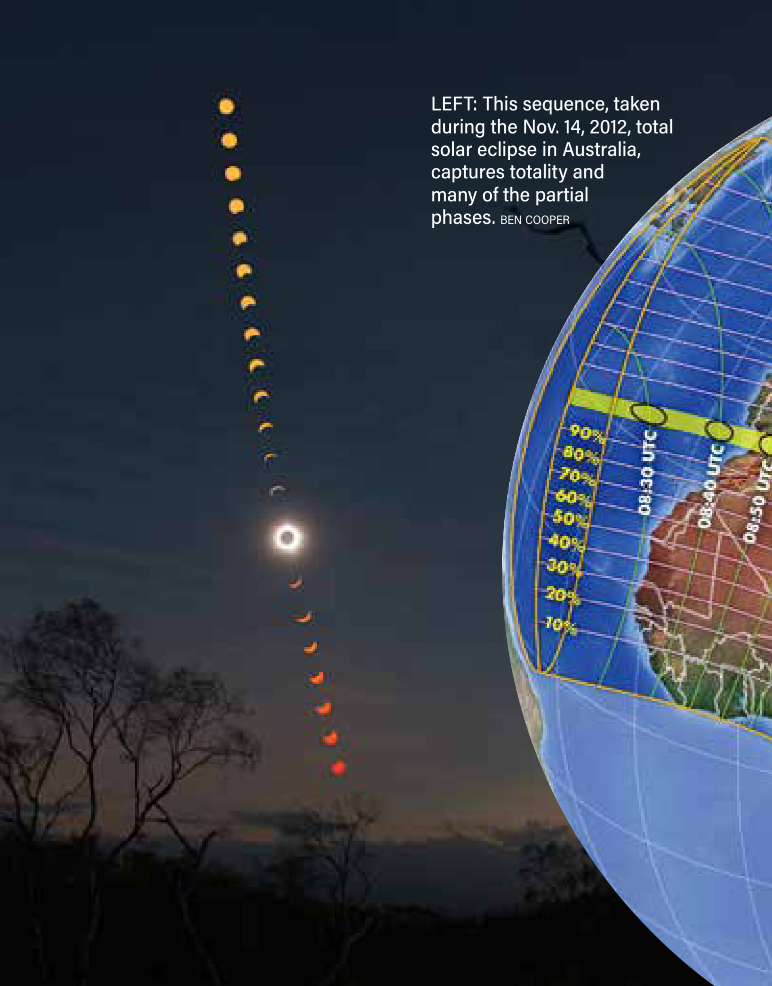
On the mainland, Temuco will undoubtedly be the destination of many eclipse chasers. From there, it's a quick drive to either Gorbea or El Liuco, both of which will enjoy 2 minutes 9 seconds of totality. One spot that might offer an intriguing photographic possibility is the southern side of Villarrica, one of Chile's most active volcanoes. The eclipse will last 2 minutes 6 seconds with the Sun 72° high in the north-northeast.

As the Moon's shadow crosses into Argentina, it encounters a vast stretch of small villages. One possibility is first traveling to Los Menucos. Then drive 50 miles (80 km) northeast to the small village of Ministro Ramos Mexía. Weather prospects throughout Argentina are best along the eastern edge of the Andes Mountains. Don't go too far west, though, because cloudiness is highest near the Chilean border.

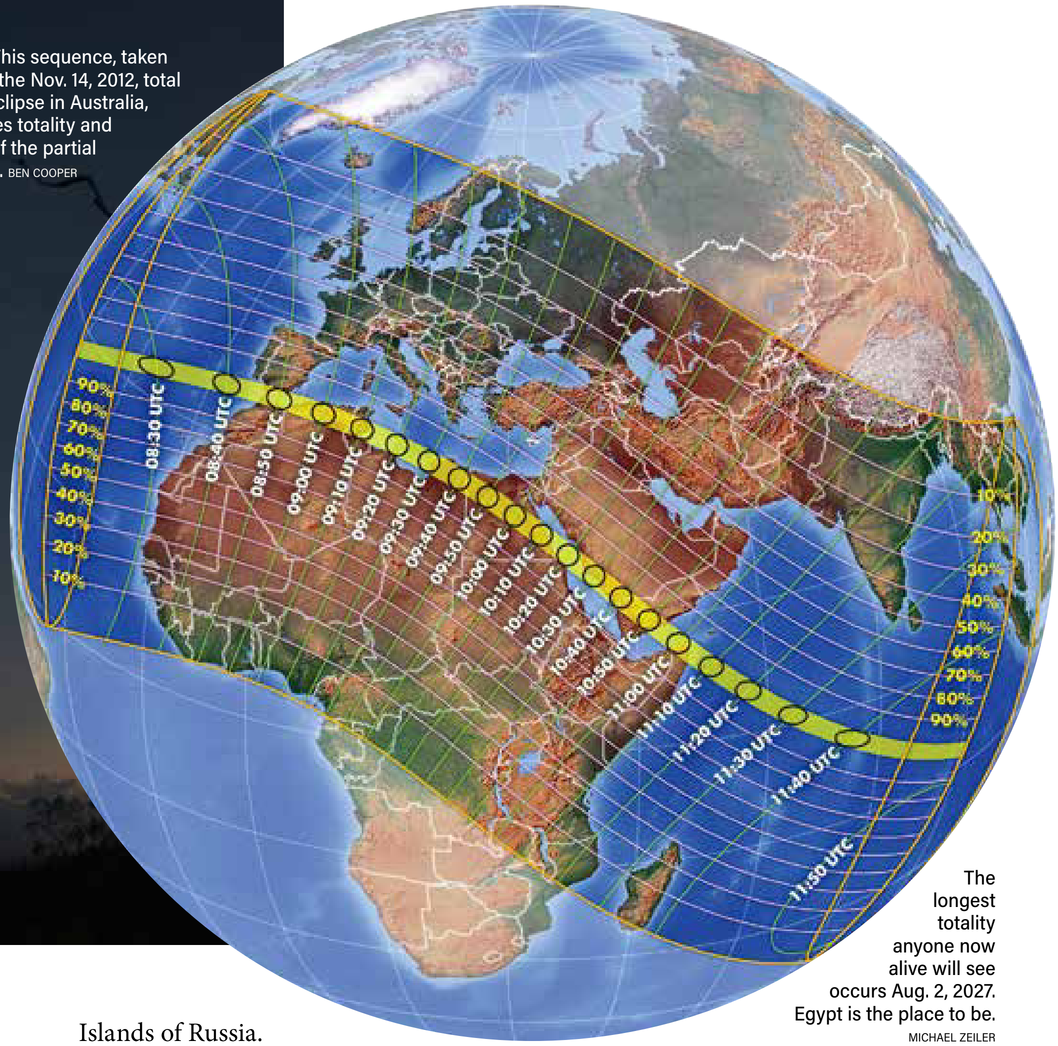
April 20, 2023

The Moon's shadow during this eclipse will touch three countries: Australia, Timor-Leste, and Indonesia. The maximum duration of totality is 1 minute 16 seconds.

The umbra first encounters Australia at the Ningaloo Coast, a popular destination for tourists. Accommodations are about 60 miles (100 km) to the north at Exmouth, which will receive 54 seconds of totality.



LEFT: This sequence, taken during the Nov. 14, 2012, total solar eclipse in Australia, captures totality and many of the partial phases. BEN COOPER



The longest totality anyone now alive will see occurs Aug. 2, 2027. Egypt is the place to be. MICHAEL ZEILER

Continuing to the northeast, the umbra next encounters Timor-Leste (or East Timor). Unfortunately, the capital city of Dili lies outside the path. Viewers on the island's eastern end will see a totality lasting only a few seconds less than the maximum duration.

Totality then moves to Indonesia at Kisar Island. The roughly 7,000 residents of the main town, Wonreli, will enjoy 1 minute 2 seconds of totality. Finally, the umbra reaches Western New Guinea. Throughout this province, totality will last 1 minute 8 seconds.

April 8, 2024

Because this eclipse crosses the U.S. from Texas to Maine, it may become the most viewed celestial event in history. The maximum duration of totality is 4 minutes 28 seconds. And because we'll write about it in great detail as the date approaches, that's all I'll say about it here.

Aug. 12, 2026

Totality will touch five countries with a maximum duration of 2 minutes 18 seconds. First up are the Saint Peter Islands of Russia. The climate in this uninhabited region is severe. Even in August, the Laptev Sea is usually obstructed by pack ice. Few, if any, people will see totality from Russia.

The umbra then heads over the Arctic Ocean to the least densely populated territory in the world — Greenland. During its trip over Earth's largest island, the Moon's inner shadow encounters no cities or towns. As with Russia, few people will view totality from Greenland.

The situation is different in Iceland. Several coastal locations lie near the longest totality. Fortunately, the Moon's umbra will cover southwestern sections of Reykjavík for 1 minute 7 seconds.

Only a minuscule part of Portugal will be covered by the umbra. Head to the border with Spain to view 21 seconds of totality. In Spain, the duration of totality will stay above 1 minute 39 seconds along the center line the whole way, but the Sun's altitude is low. The largest city in the umbra will be Zaragoza, where residents will experience 1 minute 23 seconds of totality with the Sun 6° high.

Aug. 2, 2027

This eclipse, whose umbra will touch a dozen countries, offers the longest totality anyone now alive will see — a whopping 6 minutes 23 seconds. The umbra encounters, in order, Morocco, Spain (where totality at the Rock of Gibraltar will last 4 minutes 26 seconds), Algeria, Tunisia, and Libya.

Although many eclipse chasers may head to these locations, more will watch the spectacle from Egypt. Combining a tour of this country's wonders with the eclipse will be a dream come true. Here's where the eclipse reaches its peak and where weather won't be a factor. Unfortunately, totality misses the two largest cities, Cairo and Alexandria.

Greatest eclipse will occur not quite 40 miles (64 km) southeast of Luxor with the Sun a scant 7° from the zenith. How could this experience possibly be any better? Well, imagine viewing this spectacle standing outside Karnak, the great temple complex near Luxor (losing less

than 2 seconds of totality). Next to the pyramids at Giza, Karnak is the most visited historic site in Egypt.

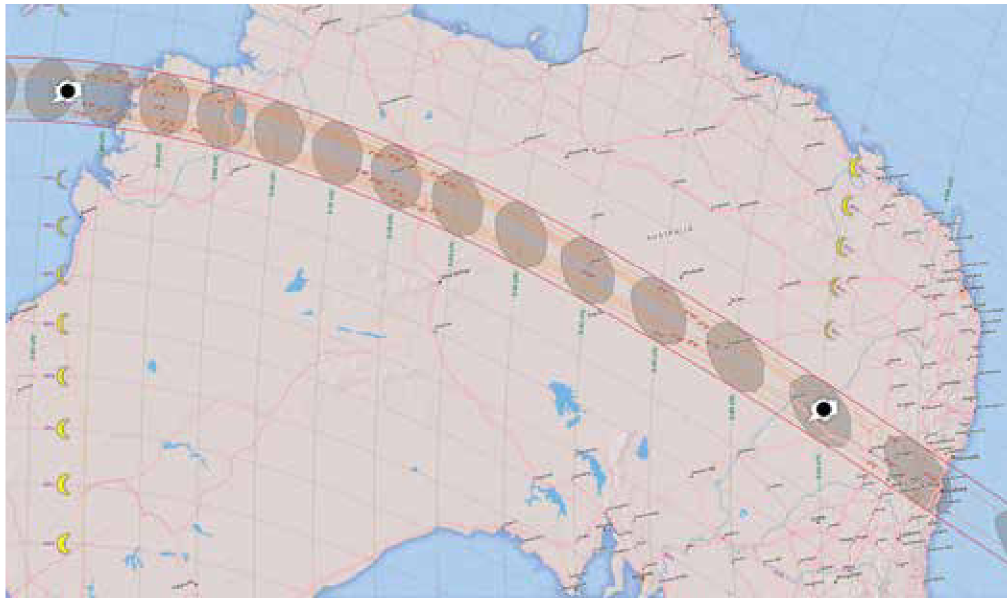
In Saudi Arabia, Jeddah will enjoy more than 6 minutes of totality. And with a total average August rainfall of 0.02 inch (0.05 centimeter), conditions should be excellent for the 4 million residents. The final three countries for this eclipse are Yemen, Somaliland, and Somalia. Along the center line in Somalia, viewers could see the Moon cover the Sun for 5 minutes 32 seconds at the northern coast.

July 22, 2028

During this eclipse, the Moon's umbra encounters just Australia and New Zealand. Maximum duration of totality is 5 minutes 10 seconds.

After traveling more than 1,800 miles (2,900 km) over the Indian Ocean, the umbra makes landfall on Australia proper in Mitchell River National Park. The greatest duration occurs less than 125 miles (200 km) from there. The best bet for an eclipse chaser might be to base in Wyndham, then drive south on the Great Northern Highway for 5 minutes 3 seconds of totality. In New South Wales, a favorable location is Bourke, which will experience 4 minutes of totality. Another is Dubbo, which gets 3 minutes 46 seconds of totality.

Then the umbra hits Sydney, with its population of 5.2 million. The city's numerous attractions offer many photographic opportunities. Perhaps the most



Totality comes to Australia on July 22, 2028. If you haven't seen the Sydney Opera House, this trip may provide the opportunity. MICHAEL ZEILER

The July 2, 2019, eclipse was total in Chile and Argentina. This photo was taken at the Cerro Pelado Dam in Argentina. FABRIZIO MELANDRI

sought-after location, and one with 3 minutes 44 seconds of totality, will be south of the Sydney Opera House. There, a camera could capture the Opera House with the eclipsed Sun 29° above it.

The Moon's umbra then tracks to the South Island of New Zealand. From here, it will appear in the northwestern sky, so the west coast will have a sight line over water. Milford Sound, New Zealand's most famous tourist destination, would be an ideal spot to set up shop. There, totality will last 2 minutes 50 seconds. The short path touches only one city, Dunedin, where totality will last 2 minutes 47 seconds with the Sun 8° high. Choose your site carefully because the central city is surrounded by a ring of hills.

Nov. 25, 2030

The path of totality during this eclipse touches five countries. Maximum duration of totality is 3 minutes 44 seconds. In Namibia, the shadow first touches the famous Skeleton Coast south of Torra Bay. A drive down the coast to the center line will yield a totality lasting 1 minute 51 seconds.

Most of the path of the center line through Botswana tracks within Gemsbok National Park. An eclipse watcher could get to the center line (2 minutes 10 seconds of totality) by driving the road that goes south from Lokgwabe or north from Tshabong.

South Africa surely will be the destination for thousands of eclipse chasers. Kroonstad, a city of around 200,000, offers a duration of totality of 2 minutes 22 seconds. From Bethlehem, whose population of 20,000 will surely swell on eclipse day, totality will last 2 minutes 25 seconds. At the coast of the Indian Ocean, the best destination might be Durban, where totality will last 2 minutes 21 seconds.

Lesotho experiences the eclipse in its northeastern region. Unfortunately, its capital, Maseru, lies south of the path and gets only a 99-percent partial eclipse. For that extra 1 percent, head north-northwest to the village of Kala, where totality will last 2 minutes 2 seconds.

In Australia, Calca and Streaky Bay will enjoy 2 minutes of totality. A good starting point for travelers is Adelaide, which lies 186 miles (300 km) south of the path. Those who drive north might consider continuing another 60 miles (100 km) to the Ikara-Flinders Ranges National Park. Careful positioning should produce spectacular pictures.

Nov. 14, 2031

The duration of totality for this hybrid eclipse (a combination of an annular and a total) is 1 minute 8 seconds, but that occurs in the central Pacific Ocean. In Panama, the only country the antumbra touches, annularity will last for 5 seconds with the Sun nearly scraping the west-southwestern horizon.

March 30, 2033

The Moon's umbra during this eclipse encounters only the U.S. and Russia. Maximum duration of totality is 2 minutes 37 seconds.

The umbra first touches the U.S. at the southern tip of Pinnacle Island in the Bering Sea. There, totality will last 2 minutes, with the Sun 4° high at mid-eclipse. On the Alaskan mainland, only four cities have populations above 10,000, but none lie in the path. The best plan will be to base in Anchorage and take a flight to Nome, where totality will last 2 minutes 29 seconds.

The eclipse in Russia takes place entirely in the eastern end of the country. Only Lavrentiya and Lorino have populations approaching 1,000. Lavrentiya will experience 1 minute 58 seconds of totality, while Lorino gets 4 fewer seconds.

March 20, 2034

The path of the umbra during this eclipse will touch 13 countries. The maximum duration of totality is 4 minutes 9 seconds.

The Moon's umbra first touches land at Porto-Novo, the capital of Benin. At the coastline of the Gulf of Guinea and the border with Nigeria, totality will last 1 minute 25 seconds.

The Moon's umbra next enters Nigeria. Lagos, a city with a population in excess of 21 million, will experience 2 minutes 52 seconds of totality. A savvy eclipse chaser might drive north from Lagos just past Sagamu, and then head east to extend totality to 3 minutes 30 seconds.

The umbra quickly passes through Cameroon and into Chad. Within 25 seconds, darkness comes to N'Djamena, Chad's capital and largest city. The roughly 2 million residents there will experience totality lasting 3 minutes 45 seconds.

The Moon's inner shadow then tracks for 500 miles (800 km) within Sudan before it finds the first populated settlement on the banks of the Nile River. One possible base is Abri. It sits on the center line and offers 4 minutes of totality.

In Egypt, the best strategy is to head for the coast of the Red Sea. Shalateen gets 3 minutes 14 seconds of totality. Many trip providers will offer tours of Abu Simbel, with its spectacular temples built by Ramesses II. Anyone there will see the Moon blot out 99.9 percent of the Sun.

After the umbra crosses the Red Sea, it enters Saudi Arabia. The best views will be from the western half of the country. Along the center line, the duration of totality drops from 3 minutes 43 seconds there to 3 minutes 10 seconds at the Kuwaiti border.

Kuwait and Iran are next. Sabah Al Ahmad Sea City, an easy drive south from Kuwait City, offers 3 minutes 9 seconds of totality. Once the path touches Iran, it quickly arrives at Shiraz. Its population of near 2 million will experience between 2 minutes 17 seconds and 2 minutes 44 seconds of totality. In Afghanistan, the single city in the path is Khost, whose 100,000-plus residents will enjoy a totality lasting 2 minutes 9 seconds.

In Pakistan, Rawalpindi and the capital of Islamabad fall under the Moon's umbra. Islamabad will enjoy 2 minutes 4 seconds of totality. Residents of Rawalpindi will get 10 fewer seconds.

Next is India. Srinagar, the country's northernmost city with a population above 1 million, experiences a totality of 2 minutes 4 seconds. China is the final country the umbra will touch, but the eclipsed Sun will be near the horizon by this point.

Sept. 2, 2035

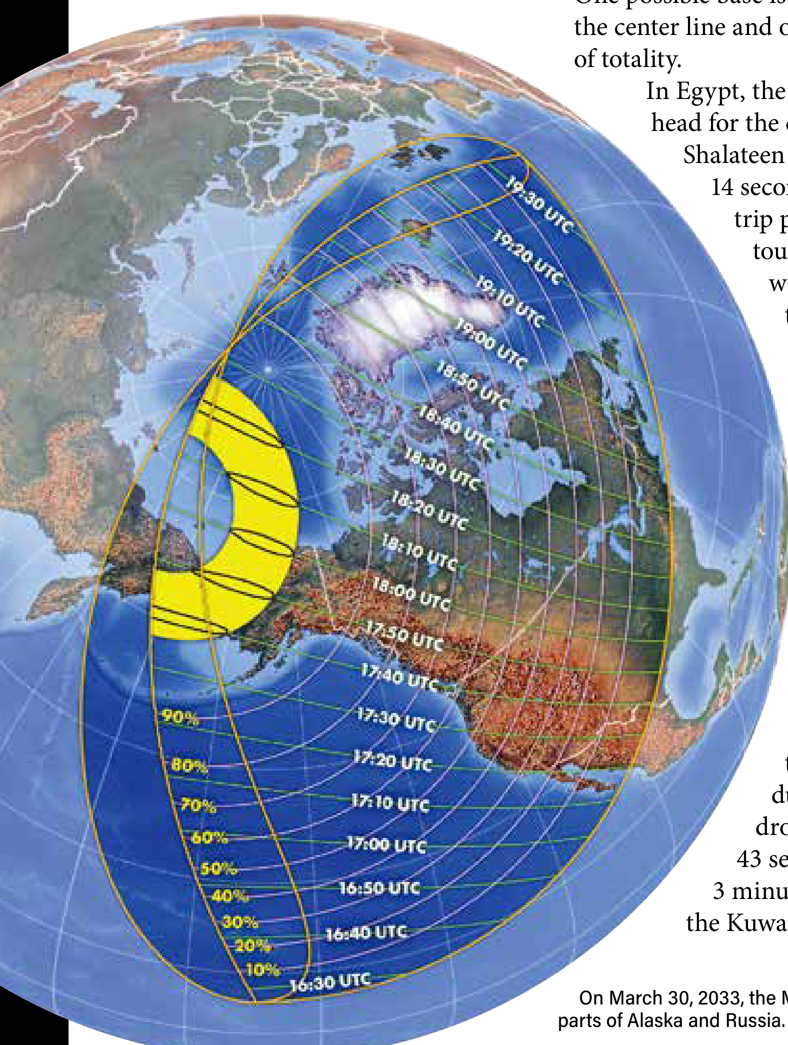
This eclipse will touch four countries, with a maximum duration of totality of 2 minutes 54 seconds.

In China, the first city under the umbra is Jiuquan, whose million residents will enjoy 51 seconds of totality. The 2 million inhabitants of Baotou will witness 49 seconds, and the 3.5 million in Datong will enjoy 1 minute 32 seconds. Then totality reaches Beijing, where the city center will experience a duration of totality of 1 minute 30 seconds with the Sun 32° high. Two more cities of note in the path are Tangshan (45 seconds of totality) and Qinhuangdao (1 minute 56 seconds of totality).

The shadow next moves into North Korea. It touches the outskirts of Pyongyang, where totality will last 1 minute 54 seconds at the northern end of the city. The umbra also covers Wŏnsan for 2 minutes 6 seconds.

In South Korea, eclipse watchers should head to the border with North Korea. At that point, totality will last 1 minute 44 seconds with the Sun over open waters toward the southeast.

Finally, the path leads to Japan, just south of Wajima. Four cities that would make good bases are Toyama, Nagano, Maebashi, and Takasaki. They offer durations of totality of 1 minute 47 seconds,



On March 30, 2033, the Moon's umbra will visit parts of Alaska and Russia. MICHAEL ZEILER

2 minutes 16 seconds, 2 minutes 13 seconds, and 1 minute 57 seconds, respectively. Unfortunately, Tokyo lies just south of the path. From downtown, the Moon will cover "only" 99.5 percent of the Sun. With so many amateur astronomers in Japan, it's certain that there will be a huge exodus northward from Tokyo.

July 13, 2037

During this eclipse, only Australia and New Zealand will experience the umbra. The maximum duration of totality is 3 minutes 58 seconds.

Totality comes to mainland Australia at Geraldton, where it will last 2 minutes 34 seconds. Drive 25 miles (40 km) south, and you'll gain an extra 21 seconds. In nearly the center of Australia, one of the greatest opportunities to photograph the eclipse will take place when totality occurs at Uluru/Ayers Rock, a massive sandstone rock formation. There, it will last 3 minutes 4 seconds with the Sun 40° high in the north-northeast. Any imager on the south-southwest side of this site could capture the eclipsed Sun above Australia's greatest natural wonder.

Finally, the path encounters Brisbane. This city's southern limit will experience 2 minutes 20 seconds of totality. Mobile eclipse watchers won't stop there, however. They'll continue south, perhaps to Rathdowney, for 3 minutes 32 seconds of totality.

Finally, the umbra contacts New Zealand's North Island. If possible, view the eclipse from the island's western end. There, totality will last 2 minutes 22 seconds with the Sun 14° above an ocean horizon.

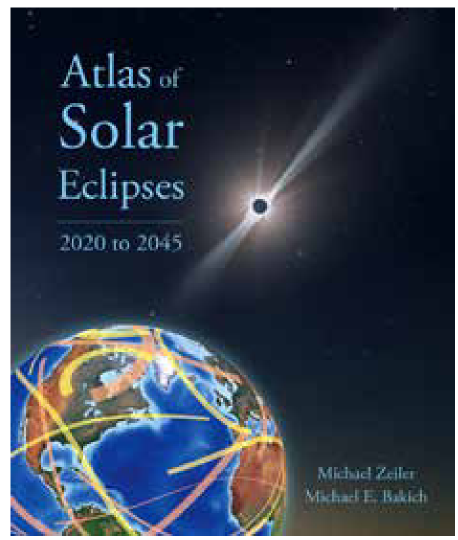
Dec. 26, 2038

As with the previous eclipse, the umbra will touch only Australia and New Zealand. The maximum duration of totality is 2 minutes 18 seconds.

It enters Australia at Onslow, which sits on the country's west coast. Anyone there will see 1 minute 4 seconds of totality. A good base will be Adelaide. Eclipse chasers heading north from there, perhaps to Burra, will enjoy 1 minute 53 seconds of totality. And at Mallacoota, which lies on the southeast coast, totality will last 2 minutes 9 seconds.

In New Zealand, the Moon's umbra touches the northern tip of the South Island, as well as the southern part of the North Island. Savvy eclipse chasers might base in the country's capital, Wellington, and then head north to the center line near Foxton, where totality will last 2 minutes and 12 seconds.

ABOVE: The total eclipse April 30, 2041, passes through the heart of Africa. MICHAEL ZEILER



RIGHT: *Atlas of Solar Eclipses: 2020 to 2045*, by Michael Zeiler and this article's author, offers much more detail about these eclipses and 41 more. You can order a copy at www.MyScienceShop.com. MICHAEL ZEILER

Dec. 15, 2039

This eclipse will be a tough acquisition for most people because it only touches Antarctica. Maximum duration of totality is 1 minute 51 seconds. The umbra misses McMurdo Station, the continent's largest settlement, by only 60 miles (100 km). Cruise lines offer tours here, but it's most likely that eclipse chasers will observe the event near its beginning, approximately 600 miles (1,000 km) south of New Zealand. From there, totality will last 1 minute 30 seconds with the Sun 10° above the ocean horizon.

April 30, 2041

This eclipse encounters five countries. The maximum duration of totality is 1 minute 51 seconds. Angola's capital, Luanda, will get 1 minute 47 seconds of totality, but the path encounters just a few more towns.

The umbra next visits the Democratic Republic of the Congo. Residents at the northern edge of Kikwit who position themselves along the bank of the Kwilu River will see 56 seconds of totality. Another large city is Butembo, whose southern edge gets 54 seconds.

In Uganda, the umbra will cover many small towns. One base is the capital, Kampala, a city of 1.7 million. From there, travelers could head north to the Extreme Adventure Park Busika, where totality will last 1 minute 15 seconds.

In Kenya, Nairobi offers many accommodations, but visitors might head to Kitale, where totality will last 1 minute 1 second. Nature lovers could observe from Wamba, where totality will last 47 seconds. The town lies just north of the Samburu National Reserve and the Buffalo Springs National Reserve, both of which contain rich wildlife populations.

The duration of totality in Somalia is 55 seconds at the country's western border and 48 seconds at the shore of the Somali Sea. Unfortunately, few towns and villages lie along the path.

Michael E. Bakich *is a contributing editor of* Astronomy *and author, with Michael Zeiler, of* Atlas of Solar Eclipses: 2020 to 2045*.*

Celebrating a century of VARIABLE STAR astronomy

Since its founding in 1911, the American Association of Variable Star Observers has been an indispensable organization for amateur astronomers, engaging stargazers in exploring the night sky.

BY STELLA KAFKA

HUMANS ARE NATURAL EXPLORERS. Once we were clothed, fed, and found shelter, we started wondering, "How does nature work? What's around us? How did we come to be? What is our place in the universe?"

To answer these questions, we developed theories about the motions of the Sun and the Moon; we predicted eclipses and discovered the principles and laws that govern the natural world. Astronomy became part of our everyday life and our culture: We used stars to navigate our planet, tell us when to rotate our crops, and define our seasons. We

FAR LEFT: This photo was taken at the Annual Meeting of the AAVSO on Nov. 10, 1917, held at Harvard College Observatory in Cambridge, Massachusetts. Among the attendees are Annie Jump Cannon (seated, third from the left) and Henrietta Swan Leavitt (seated, fourth from the left). The association's founder, William Tyler Olcott, is directly behind Ida E. Woods, the woman standing in the front row. AAVSO

LEFT: The AAVSO has a long and storied history. This year, the organization celebrates its 110th anniversary. AAVSO

BELOW: Since the first AAVSO annual meeting in 1916, the event has grown immensely. This photo shows more than 70 attendees at the 108th Annual Meeting of the AAVSO in Las Cruces, New Mexico, which took place in October 2019. (The more recent 109th Annual Meeting was held virtually due to the pandemic.) The author stands third from the right in the front row. AAVSO

incorporated starry nights and comets into our art. And early on, we noticed that some stars change their brightness in systematic ways. We recorded these stars in our most valuable historical and religious documents for posterity.

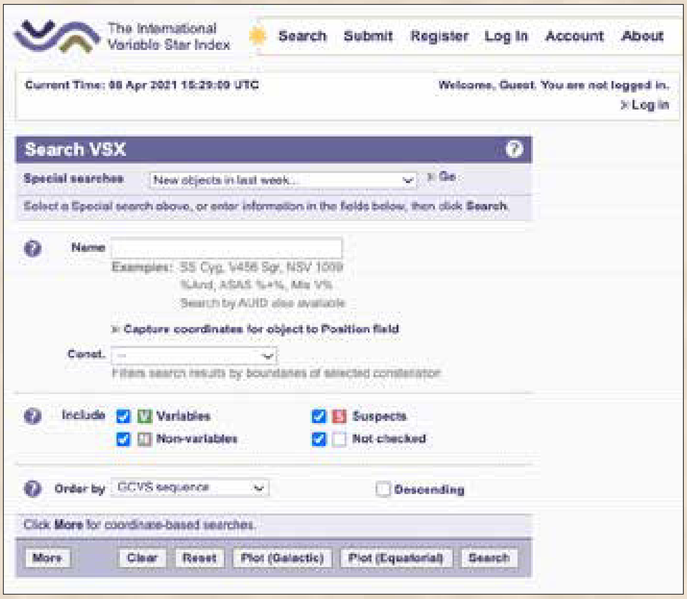
Variable star observers

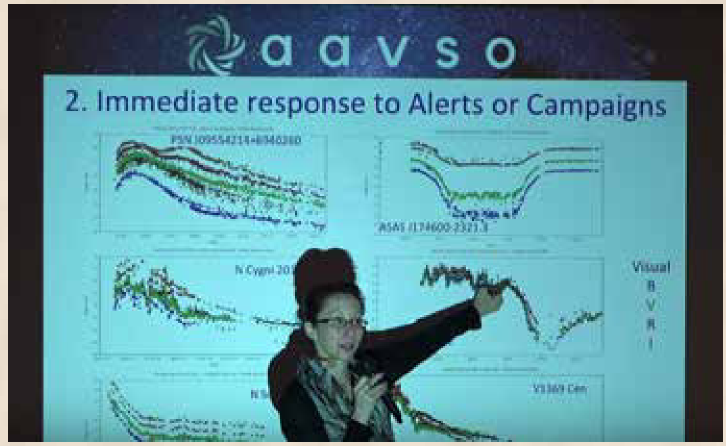
Over time, astronomy became a profession for some and a hobby for others. Researchers started forming groups of like-minded enthusiasts to observe the sky, attend lectures, and discuss recent discoveries. Within those groups, they started discussing whether there was a way for those without formal preparation — amateur astronomers — to participate in scientific discovery.

In 1911, amateur astronomer William Tyler Olcott officially formed the American Association of Variable Star Observers (AAVSO) under the guidance of Harvard College Observatory Director Edward C. Pickering. The association's purpose was to assist and organize amateur astronomers to collectively work to observe and understand some of the most dynamic and fascinating objects in the universe: variable stars.

Variable stars undergo brightness changes for reasons that are part of their nature and have nothing to do with cloud cover or flickering caused by Earth's atmosphere. By continuously observing those changes, we can discover intrinsic properties of these stars, understand their mechanics, and derive the physical laws describing their behaviors.

The AAVSO has become an invaluable resource and enabler of this type of research. As scribed in our incorporation document, "the Corporation is constituted for the purpose of the promotion of Variable Star Astronomy and kindred objects." This statement showcases the foresight of our founders, who recognized that variable stars could not be the only celestial objects that changed in brightness. They wanted to give flexibility to future researchers and observers, allowing them to participate in relevant research on any new and exciting discoveries using whatever means human ingenuity enabled.





ABOVE: The author gives a talk for an audience of professional astronomers on the value of AAVSO observations, at a September 2019 conference in Yerevan, Armenia. STELLA KAFKA

UPPER LEFT: Observers have a number of resources available at their fingertips on the AAVSO website, including tools to generate light curves (LCG), complete photometric analysis (VPhot), plot variable star finder charts (VSP), and visualize and analyze data (VStar), as well as the International Variable Star Index (VSX) and a tool to submit observations to the AAVSO (WebObs). These resources can be found at www.aavso.org/observers. AAVSO

LEFT: VSX currently contains information on more than 2 million variable stars. Users can search for available data on stars in VSX or submit their own observations. Submissions are entered into a queue and peer reviewed before being cleared for the database, to ensure quality control. AAVSO

Over the decades, AAVSO observers — aided by technological advances and access to sophisticated equipment — have progressed alongside professional astronomers in their quest for knowledge. AAVSO observers started with visual observations, with or without the aid of binoculars or a telescope, to compare the brightness of variable stars with non-variables. They sent their reports to the AAVSO Headquarters in Cambridge, Massachusetts, for inclusion in the AAVSO International Database (AID).

Evolving technology slowly began to enrich these successful visual observations. In the years following World War II, the AAVSO started our Photoelectric Photometry program, encouraging members to use emerging technology to obtain high-precision data on bright variable stars. This dramatically increased the accuracy of observations for those stars and added a new component for AAVSO observers: It enabled them to acquire data using filters, including colors, as opposed to naked-eye only observations.

Community and communication

An essential part of the AAVSO has always been building an international community of individuals united under the umbrella of astronomy. The organization's eagerly anticipated annual meetings, starting with the first one in November 1917, are places to exchange ideas, celebrate scientific results achieved with AAVSO data, build new friendships, and "geek out" together. In 1972, the AAVSO founded the *Journal of the American Association of Variable Star Observers* (JAAVSO) to disseminate information from scientific presentations given at the AAVSO meetings. The journal also welcomed content on variable star scientific discoveries, authored by both professional and amateur astronomers.

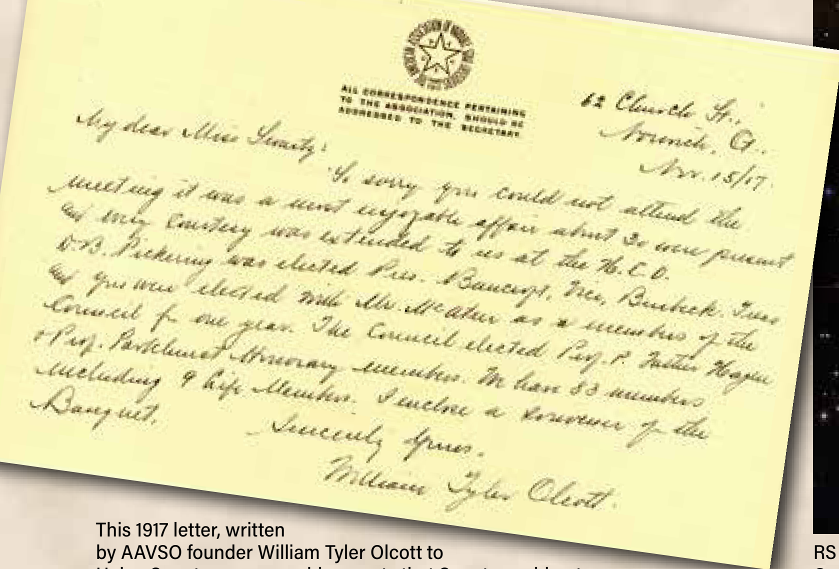
As the internet provided the means for immediate communication, mailed letters, paper alerts requesting observations, and telegrams were replaced by email groups, digital alerts, and online forums. Requested data became instantly available. Observers shared targets immediately and participated in animated discussions and clarifications on observing campaigns. Our international community started communicating in real time.

Keeping up with the times

By the last decade of the 20th century, instruments, filters, and larger telescopes had become even more affordable to citizen astronomers. In the 1990s, our observers started attaching CCD cameras to their telescopes, pushing their observing capabilities to ever-fainter objects. They began purchasing various filters to provide color information on stars of interest. And they started using DSLR cameras for data acquisition.

By the early 2000s, appropriate software tools became essential to extract photometry, access star-finding charts with suitable comparison stars, submit observations online, and discuss and publish results. The AAVSO adjusted to these new demands by focusing on our online

In 1944, when World War II disrupted Europe's scientific activities, the AAVSO formed its Solar Division to monitor sunspots. This later evolved into the modern-day AAVSO Solar Section, which provides observations for the independently derived American Relative Sunspot Numbers used by solar researchers worldwide.


ALL CORRESPONDENCE PERTAINING TO THE ASSOCIATION, SHOULD BE ADDRESSED TO THE SECRETARY

62 Church St.,
Norwich, Ct.
Nov. 15/17

My dear Miss Swartz:

So sorry you could not attend the meeting it was a most enjoyable affair about 30 were present & every courtesy was extended to us at the H.C.O. E.C. Pickering was elected Pres. Bancroft, Vice, Burbeck, Treas & you were elected with Mr. McAteer as a member of the Council for one year. The Council elected Rev. Father Hagen & Prof. Parkhurst Honorary members. We have 83 members including 9 Life Members. I enclose a souvenir of the Banquet.

Sincerely Yours.
William Tyler Olcott.

This 1917 letter, written by AAVSO founder William Tyler Olcott to Helen Swartz, expresses his regrets that Swartz could not attend the 1917 meeting. It also informs Swartz of her election as a council member of the organization, along with Charles McAteer, for the following year. AAVSO

RS Puppis, imaged here in stunning detail by the Hubble Space Telescope, is a Cepheid variable whose brightness varies by roughly a factor of five every 41 days. NASA, ESA, AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)-HUBBLE/EUROPE COLLABORATION. ACKNOWLEDGMENT: H. BOND (STSCI AND PENN STATE UNIVERSITY)

presence and offered resources. We expanded our educational and training portfolio to include manuals disseminated through our website, online courses, and a peer-mentoring group. We also developed software to facilitate data analysis.

In 2006, with the help of volunteers, we built our Variable Star Index (VSX) — a supercatalog of current information on variable stars, which has become the backbone of our databases and a valuable reference for researchers worldwide. We formed an active help desk to immediately assist observers. And we started focusing even more closely on data validation, providing feedback to observers when we find discrepancies. The latter is a primary reason why professional astronomers trust our database — we are thorough.

And the professional astronomical community's trust in our work has only increased. More and more professional astronomers request AAVSO observers' help to collect and analyze critical data for their research. We have joined high-profile international collaborations, including with the Transiting Exoplanet Survey Satellite (TESS) and the All Sky Automated Survey for SuperNovae (ASAS-SN). We have initiated two new databases — for exoplanets and for spectroscopy — to accommodate small telescope data for these fields and expand the impact of our observers' data in these areas. And we are now accepting relevant data using the new generation of detectors: CMOS cameras. We are interested in exploring the use of such equipment, especially as manufacturers indicate they may begin phasing out support for CCDs.

The AAVSO itself has also grown with time. Our AID photometry database now hosts more than 44 million data points, with 2 million of those collected in 2020 alone. VSX contains more than 2 million stars. Our data appear in a multitude of peer-reviewed astronomical manuscripts and press releases, while our observers are the superstars among groups of scientific collaborators, thanks to their ability to uniquely respond to alerts and provide data from all over the world. As large space- and ground-based professional photometric surveys reveal new stellar wonders, we are invited to pursue them. The observers, volunteers, researchers, educators, and students of the AAVSO are more essential than ever for the progress of science. We live in the renaissance of variable star astronomy.

THE AMERICAN ASSOCIATION OF VARIABLE STAR OBSERVERS
AAVSO
FOUNDED 1911

Join us!

Astronomy is a scientific field where non-specialists can make a meaningful contribution to research with visible impact. If you have access to binoculars, a telescope, a DSLR camera, a CCD camera, or a spectrograph, join us. If you are interested in learning more about variable star work, register for our free webinars. If you are working on a project as part of your student coursework, publish it in the JAAVSO. If you want to learn how to observe with various techniques, we have all the necessary material to help you get started, and we will be by your side as you engage with the projects of your choice. Take advantage of our free resources. Join the conversations.

Whether you are an astronomy enthusiast, an observer, a learner, or an explorer, become a member and join our quest for knowledge. When it comes to understanding the cosmos, one of the only means we have in our hands is light — which, when studied the right way, can reveal a four-dimensional picture of some of the most dynamic and diverse phenomena in the universe!

Oct. 10, 2021, marks 110 years of the AAVSO's work and contributions. It's been 110 years of hard work, building a unique community of astro-enthusiasts who collectively explore the universe and actively participate in scientific discovery. Those individuals leave a rich legacy of knowledge and an outstanding personal contribution to science. Anyone can do it, and the AAVSO is here to help you start your journey exploring the stars. Join us!

Stella Kafka *has served as CEO of the AAVSO since 2015. She holds a Ph.D. in astronomy and is passionate about building inclusive communities through science.*

Explore the sky with **Oberwerk binoculars**

High-quality optics, comfortable eyepieces, and impressive features make the 20×65 ED Deluxe binoculars ideal for any astronomer. BY PHIL HARRINGTON

THOSE READERS FAMILIAR with my Binocular Universe column may recall my monthly sign-off line, "Two eyes are better than one." That's not just a cliché; that's my mantra. Ever since I became interested in astronomy, binoculars have been by my side. While I have owned many telescopes over the decades, binoculars have remained an important part of my equipment arsenal.

That's why I was especially excited to review Oberwerk's 20x65 ED Deluxe binoculars. Oberwerk, German for "above work," broke onto the scene in 1999 as a small online retailer founded by Kevin Busarow. More than two decades later, Oberwerk continues to market quality binoculars for every budget.

The dual f/6 objective lenses of the 20x65 ED Deluxe binoculars deliver sharp, clear observing. COURTESY OF OBERWERK

Breaking them down

The 20x65 ED Deluxe binoculars, introduced about three years ago, are built around a unique combination of 65mm-diameter objective lenses and 20x magnification. Most 20x binoculars come with 80mm objectives, although a few have 70mm and even 60mm objectives. The smaller 65mm aperture will produce slightly dimmer images. Together, they help to darken the field and improve image contrast, especially in areas suffering from light pollution, thanks to the smaller 3.25mm exit pupil.

Optically, the heart and soul of the 20x65s are twin f/6 objective lenses. The objectives feature a two-element design, one of which is made from extra-low dispersion (ED) glass. As with refracting telescopes, binoculars that use non-ED objectives suffer from color fringing around bright objects, caused by chromatic aberration. ED glass delivers sharp images free of this false coloring.

Like all better-quality binoculars using the Porro prism design, the Oberwerk 20x65s feature prisms made of BaK 4 (barium crown) glass. BaK-4 prisms transmit brighter, sharper images because nearly all the light that enters the prism assembly is reflected along the intended optical path; very little light is lost. This is what optical designers call "total internal reflection."

The eyepieces are a modified-Erfle design using five lens elements set in three groups. They produce an apparent field of view measuring 65°, with a real field spanning 3.2° of sky.

The 20x65s are fully broadband multi-coated, meaning every air-to-glass surface — from lenses to prisms — has multiple layers of broadband coatings that improve light transmission and suppress flaring. The waterproof barrels are sealed, purged, and filled with dry nitrogen to prevent internal fogging, even in damp conditions.

Adding all this together, the 20x65s have all the right stuff optically.

Mechanically, the binoculars are also well made. They feature two-tone aluminum barrels measuring 15 inches (38.1 cm) long, including the eyepieces. That's a little longer than a 2-liter soda bottle. The barrels are 8.5 inches (21.6 cm) wide. The back halves of the barrels are dark olive green with a thin rubber armor coating, while the front halves toward the objectives are painted black. The barrels feature ergonomic hand grips around the prisms but, given the dimensions and weight (6.4 pounds [2.9 kilograms]), the 20x65s need to be mounted on a tripod or other external support for best results. Believe me, I tried.

But Oberwerk obviously doesn't expect you to hold them up by hand like traditional binoculars. They wisely incorporated a sliding tripod mount on a central rail between the two barrels, allowing the user to balance the binoculars on their mount. Since the mount

M42, better known as the Orion Nebula, is a perfect winter sky stop with these binoculars. RODNEY MICHAEL

attaches directly to a tripod head, an L-shaped tripod adapter is not necessary.

To ensure that no nitrogen leaks out of the barrels, the 20x65s feature individually focused eyepieces. Focusing is precise, requiring just the right amount of effort to turn the eyepieces. When I tried them, there was no backlash or wobble when focusing. The eyepieces proved comfortable to view through, thanks in part to foldable rubber eyecups around each.

The eyepiece cups must be folded back if you need to wear eyeglasses for viewing. According to Oberwerk, the 20x65s have 18mm of eye relief, which is the distance from an eyepiece's outer lens that you must position your eye to take in the full field of view. The Oberwerk eyepieces are recessed in their housings by 0.11 inches (3 mm), reducing the available distance to 15mm. I normally observe without glasses, even though I am nearsighted. To test the binoculars' viewing comfort, however, I tried viewing with my glasses on and found that I had no trouble seeing the entire field.

To take in that full view, a binoculars' interpupillary distance (IPD) must be adjusted to match the distance between the observer's eyes. In the case of the 20x65s, the IPD can accommodate a range between 2.2 to 2.9 inches (5.6 to 7.4 cm), a good range of adjustment.

In the field

When the binoculars first arrived, I put them through a series of daytime tests to check for common optical flaws such as astigmatism, field curvature, and barrel distortion. Apart from a slight bit of the latter, the terrestrial views were nearly textbook perfect.

The curse of the new binoculars was in full swing when I received these for testing last winter, thanks to an almost interminably long string of clouds and storms. But when the skies finally cleared, my perseverance paid off handsomely. The views through the 20x65s were striking. Focusing each eyepiece with the binoculars affixed to my Manfrotto tripod was easy, even while wearing heavy gloves.

My first stop with any new instrument on a winter's night is always the Orion Nebula (M42). The binoculars' 3.2° real field encompassed the entire sword, framing a beautiful vista. The four stars of the Trapezium buried inside the nebula were resolvable, surrounded by the encircling cloud. To the north, the detached portion of the Orion Nebula, separately cataloged as M43, was also clear, as was the soft collective glow of NGC 1973/75/77 and beyond that, the open cluster NGC 1981.

Another stopping point is the Pleiades (M45). They nearly filled the field, producing yet another striking view. Perseus' Double Cluster was also a delight, with several stars showing off their true colors.

Putting the 20x65s to the test, I swung toward the Crab Nebula (M1). From my light-polluted backyard, seeing M1 is usually challenging through binoculars, yet these revealed it readily.

I then moved southward to Sirius to test just how well the optical system suppresses chromatic aberration. Sirius is a tough test, owing to its point-source intensity. But sure enough, it sparkled like a perfectly white stellar diamond.

The edge of the Moon is also unforgiving when testing for false-color suppression. On another night, I checked out the First Quarter phase and could detect only the slightest hint of chromatic aberration. If I had not been specifically looking for it, I probably would not have even noticed. The optical system also curbed reflections and ghost images perfectly.

All in all, I came away very impressed with the Oberwerk 20x65 ED Deluxe binoculars. The views were sharp and clear no matter where I aimed. When you add in the price, which I judge as a bargain for what you get, these would make a great addition to any amateur astronomer's collection.

Phil Harrington *is a contributing editor of* Astronomy *with extensive observing experience using telescopes and binoculars.*

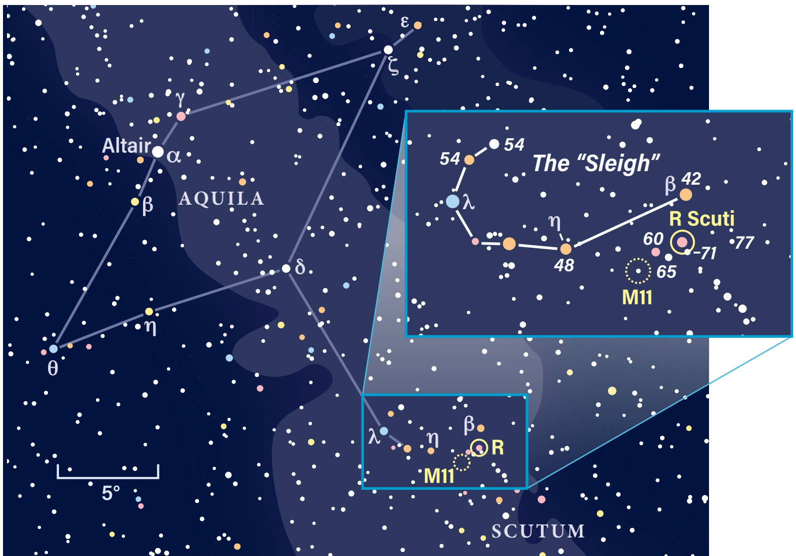
PRODUCT INFORMATION

Oberwerk 20x65 ED Deluxe Binoculars

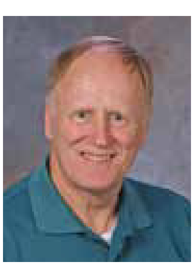
Front lenses: 2.56 inches (65 mm)
Magnification: 20x
Eye relief: 18mm
Interpupillary distance: 2.2 to 2.9 inches (5.6 to 7.4 cm)
Field of view: 3.2°
Dimensions: 15 by 8.5 by 3.5 inches (38.1 by 21.6 by 8.9 cm)
Weight: 6.4 pounds (2.9 kilograms)
Price: $519.95
Contact: Oberwerk Corporation
1861 Wayne Ave.
Dayton, OH 45410
937.640.1040
www.oberwerk.com

A variable delight

Target the pulsating stellar giant R Scuti.



The "Sleigh" asterism, which harbors several variable stars, hovers just above R Scuti. The numbers listed next to some of the stars show their magnitudes at the time of writing. Decimal points are omitted to avoid confusion with other stars. For example, the "48" below Eta [η] Scuti indicates that star has a magnitude of 4.8. ASTRONOMY: ROEN KELLY, MAGNITUDES COURTESY OF AAVSO



BY GLENN CHAPLE

Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

I timed this column to coincide with a feature article in this issue about the American Association of Variable Star Observers (AAVSO), written by the organization's director, Stella Kafka. If you haven't already read it, turn to page 54 and do so now. Then come back here, and I'll give you a basic rundown on how to observe visual variable stars.

Let me begin by sharing my own experience with observing variable stars and the AAVSO. I joined the AAVSO back in the summer of 1980, thanks to a chance meeting at Stellafane with then-director Janet Mattei. Her contagious enthusiasm for variable star observing convinced me to become a member. Since then, I've forwarded nearly 80,000 visual brightness estimates of variable stars to the organization. Of the many variables I've monitored, one of my favorites is the pulsating yellow giant **R Scuti**. It was the first variable star for which I sent brightness estimates to the AAVSO, and it's one of the easiest to observe. Now, I'd like to introduce you to this engaging, dynamic star.

R Scuti was one of the earliest variable stars discovered, with its brightness changes first reported in 1795 by English astronomer Edward Pigott. It's categorized as a RV Tauri variable — a group of pulsating stars that exhibit alternating shallow and deep dips in brightness. At its brightest, R Scuti shines somewhere between magnitudes 4.5 and 5.0. The dips alternate between magnitudes 6.5 to 7.0 and 8.0 to 9.0. That behavior is irregular, too, even grinding to a standstill now and then. An average cycle between deep minima spans about 146 days.

You can view the whole show with nothing more than a standard pair of binoculars or a small, rich-field scope. I strongly urge you to try your hand at tracking the changes in R Scuti's brightness over the next few months.

Your first step is to find R Scuti. Before going outside, get a feel for its general location by referring to our Star Dome map on page 34. R Scuti's parent constellation, Scutum, is rather faint and obscure, but you can find it southwest of the prominent constellation Aquila. A line traced from Gamma (γ) Aquilae to Delta (δ) Aquilae and extended roughly an equal distance beyond brings you to Lambda (λ) Aquilae, which is a few degrees east and slightly north of the open cluster M11. R Scuti is conveniently located near this cluster. In fact, on the Star Dome map, R Scuti is the unlabeled star that appears near the upper-right portion of the dashed circle marking M11.

Once outside under the real night sky, trek from Gamma to Lambda Aquilae with your binoculars. Lambda is the brightest star in a sleigh-shaped asterism that ends with the star Beta (β) Scuti. M11, which appears as a fuzzy patch in binoculars, lies about 2° south-southeast (below and slightly left) of Beta. Immediately northwest (above right) of M11 is a small trapezium of stars that includes R Scuti. This entire group is shown in the close-up chart on this page.

After you've found R Scuti, it's time to estimate its brightness. The chart shows the magnitudes of other nearby stars, with decimal points omitted to avoid being mistaken for stars themselves. Make your brightness estimate of R Scuti by seeking a neighboring star of the same magnitude. If that's not possible, and it usually isn't, look for "bracketing" stars — one that's slightly brighter and one that's slightly fainter than your target — then interpolate the magnitude. Because R Scuti's variations occur over months, there's no need to observe it every night; clouds won't allow that luxury anyway. I generally check out R Scuti once every five to seven nights.

Don't forget to be patient!

Don't forget to be patient! Your first encounter with R Scuti may require 30 minutes to locate the star and estimate its brightness. But the next time you try, you'll likely accomplish the task in half the time. Eventually, you'll be able to complete the entire process in minutes. Each visit, note the calendar date, time, and magnitude on a log sheet. Also keep in mind that AAVSO observers use the Julian date and time.

Having spent a half a century as an avid amateur astronomer, I guess you could say I've "been around the galaxy." However, if asked what is the most rewarding of my astronomical endeavors, I would say it's variable star observing — especially considering my decades-long association with the AAVSO. That all began with R Scuti, and I hope this ever-changing yellow giant will likewise introduce you to a lifelong adventure with variable stars.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: a small telescope tour of Lyra. Clear skies!

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INDEX *of* ADVERTISERS

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NASA's Perseverance rover will leave sealed tubes containing rock and soil samples on Mars' surface, as seen in this artist's concept. Future missions will eventually collect the samples. NASA/JPL-CALTECH

Collecting Mars samples

Q PERSEVERANCE WILL COLLECT SAMPLES IN SMALL METAL TUBES THAT IT WILL LEAVE ON THE SURFACE OF MARS FOR FUTURE TRANSPORT TO EARTH. ISN'T THERE THE RISK OF THE TUBES BEING COVERED BY DUST STORMS, MAKING THEIR RECOVERY IMPOSSIBLE?

João Miguel Matos
Setubal, Portugal

A Dust storms are a frequent occurrence on Mars. In addition to the smaller storms that occur every year, there are also, on average, three global storms per 10 Mars years — which can kick up enough dust to be seen by telescopes on Earth. So dust is constantly being lifted into and falling out of the martian atmosphere, rearranging dust on the surface.

All Mars surface missions have experienced varying levels of dust accumulation. However, some places naturally see less dust fall from the sky or have strong seasonal winds or dust devils that clean our instruments. And thankfully, Perseverance has landed in Jezero Crater — a spot relatively clear of thick surface dust — giving us confidence that the rate of dust deposition is so low that the sample tubes should be safe from burial for decades to come.

That isn't to say the samples are impervious to martian dust. If Perseverance placed them next to an active sand dune, which can move up to several meters in a Mars year, they could still be buried. But, of course, we'll make sure the locations of our sample caches are nowhere near any such dangers!

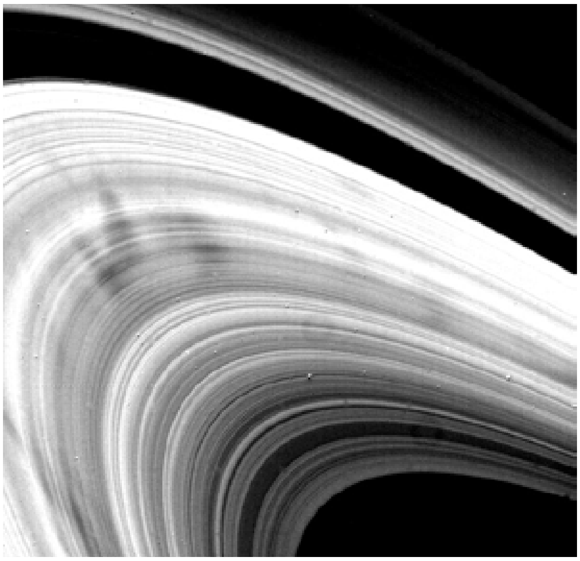
Claire Newman
Atmospheric Scientist, Aeolis Research, Liskeard, Cornwall, U.K.

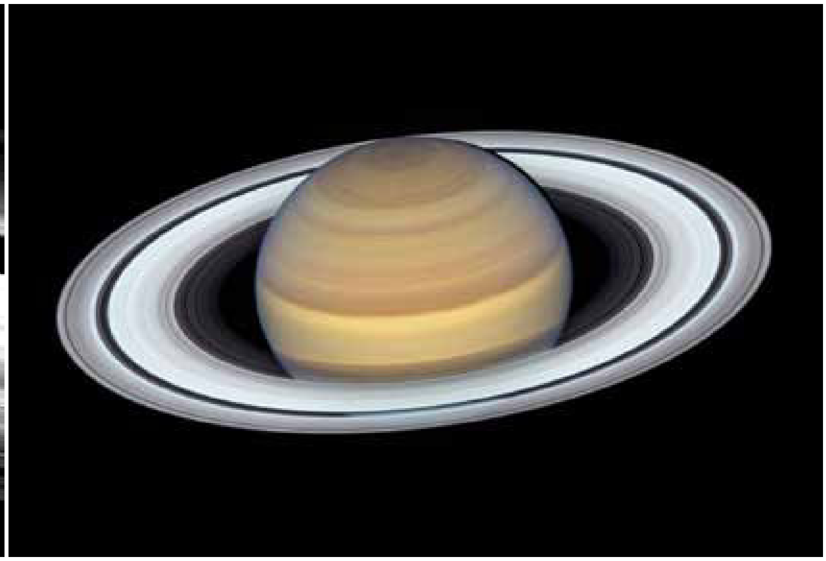
Q IN YOUR JULY 2020 ISSUE, THERE WAS A PICTURE OF ASTRONAUTS KJELL LINGREN AND SCOTT KELLY ON BOARD THE INTERNATIONAL SPACE STATION (ISS). IN THE PICTURE, SCOTT KELLY HAS A WRISTWATCH ON. WHY DOES HE NEED ONE AND WHAT TIME IS IT ON THE ISS?

Steve Kalafarski
Cranston, Rhode Island

A Actually, I wore two watches, which isn't unusual for astronauts on the ISS. One is a sleep experiment data-collection device that measures motion and light, sensing when you're asleep and how sound that sleep is. The other, as you guessed, is a watch.

We did still have time aboard the ISS and we use Greenwich Mean Time (GMT) — the time at the Royal



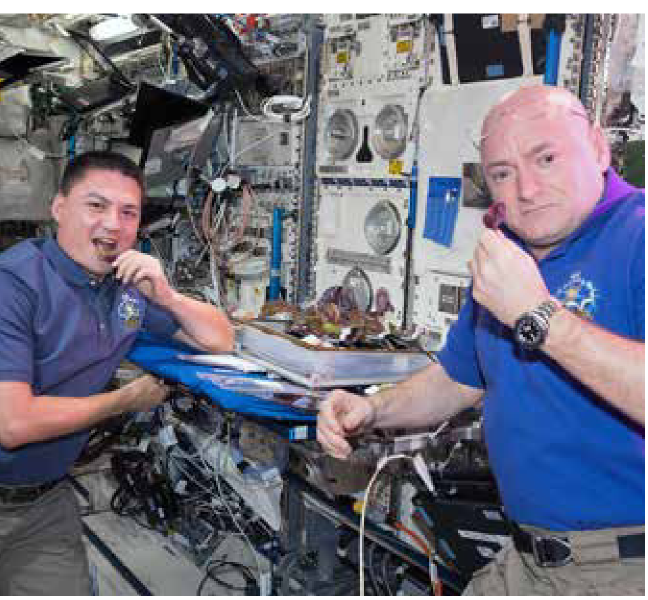


TOP: From a distance, Saturn's rings appear solid and perfect (right). But closer inspection reveals their true nature (left). NASA/JPL-CALTECH; NASA, ESA, A. SIMON (GSFC), M.H. WONG (UNIVERSITY OF CALIFORNIA, BERKELEY) AND THE OPAL TEAM

Observatory in Greenwich, London, U.K. Mission control centers around the world and across multiple time zones need to coordinate schedules for activities, so we do need a standard time.

If you're wondering how often I would have to adjust the time, the answer is, not very often on a precise watch. This is actually something we learned thanks to NASA's landmark Twins Study. My understanding, based on calculations done by civilian scientists, is that over the course of my year in space, time slowed down for me by a few milliseconds as compared to my twin brother, Mark, also a former NASA astronaut, on Earth. So, I got that going for me.

Scott Kelly
Former NASA Astronaut,
Former Commander of the International Space Station, Space



LOWER LEFT: Astronauts Kjell Lingren (left) and Scott Kelly enjoy some space-grown veggies aboard the International Space Station. Kelly can be seen sporting one of the two watches astronauts usually wear. NASA

Q | WHY DO SATURN'S RINGS APPEAR PERFECT, WITHOUT BLEMISH OR IRREGULARITY, IF THEY ARE COMPOSED OF PARTICLES THAT RANGE FROM AS LARGE AS A HOUSE NEXT TO GRAINS OF SAND?

George Thomas Holtsnider
Bremerton, Washington

A | Saturn's rings are a very orderly system. In panoramic images, they appear to be a generally flat disk with concentric structures. And yet the number of particles within the rings is similar to the number of grains of sand on Earth, each one on its own orbit around Saturn.

The reason the rings appear so uniform is a combination of effects, including gravity and collisions among the ring particles themselves. While the planets may look perfectly spherical, they all bulge slightly at the equator — a result of their spin. The gravity of the bulge affects the particles in Saturn's rings, creating an orbital plane within which the ring material tends to remain. That isn't to say that some of the particles don't deviate from this norm, but because the rings are packed with material, collisions occur commonly and tend to enforce that norm by curbing their deviated velocities, ultimately keeping most particles within the plane. This explains why ring structure appears so uniform from a distance.

And yet, when viewed in close detail, Saturn's rings are quite rich in structure. Data from the Voyager and Cassini missions reveal an abundance of tightly wound spiral waves, vertical corrugations, sharp-edged gaps, and more.

Matthew Tiscareno
Senior Research Scientist, SETI Institute, Mountain View, California

SEND US YOUR QUESTIONS

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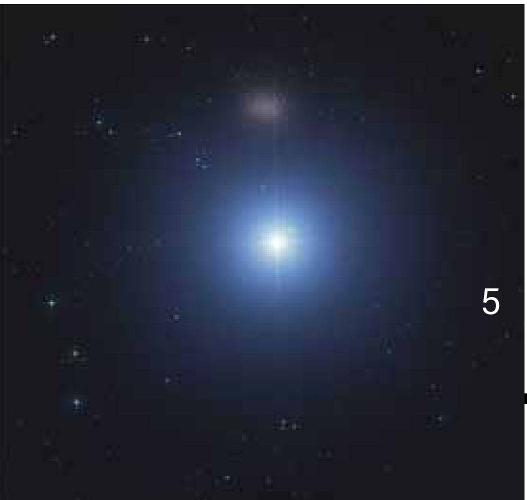
Cosmic portraits

1. TANGLED UP IN BLUE
Eerie blues and yellows put a new spin on these familiar objects: the Orion Nebula (M42), De Mairan's Nebula (M43), the Horsehead Nebula, and the Flame Nebula (NGC 2024). The image was processed with an unconventional "OHS" filter palette, mapping OIII to red, Hα to green, and SII to blue — the reverse of the popular SHO combination made famous by Hubble. The photographers reported that Hubble palette and true color versions "did not really make the objects pop as much."
*• **Antoine and Dalia Grelin***

2. CARINA'S GEM
NGC 3293 is an open cluster on the fringes of the Carina Nebula, blazing with hot, blue stars as young as 8 million years old. This image comprises 11 hours and 40 minutes of total exposure from a 17" scope in LHαRGB filters. *• **Bernard Miller***



3. A SADR DISPLAY
The Sadr Region is a region of nebulosity surrounding its eponymous star, also known as Gamma (γ) Cygni, seen at left center. This image was taken with a 3.2-inch refractor and over 15 hours of exposure in Hubble palette filters.
• John J. Kroon

4. UNDER THE STORM
Viewing aurorae from directly below the showers of energetic particles bombarding Earth's atmosphere can lead to spectacular views, with shimmering waves of color appearing to emanate from a radiant point. The photographer captured this image in Alaska with a Canon ESO R and a four-second exposure at f/2.0 and ISO 1600. ***• Mike Prestigiacomo***

5. REGULUS' SIDEKICK
The dwarf galaxy Leo I is one of the Milky Way's most distant satellites and glows at magnitude 10. It's also just 12' from magnitude-1.4 Regulus, making it a challenge to observe. The photographer took this LRGB image with a 16-inch scope and about four hours of exposure.
• Kfir Simon

6. HIGHER AND HIGHER
A Full Moon rises over the fields of Mourmouri in Ilam province in southwestern Iran on March 28, 2021, gaining brilliance as it climbs out of clouds and haze. Each of the 16 frames in this composite were 1/25-second exposures at ISO 100.
• Arman Moradi Fard

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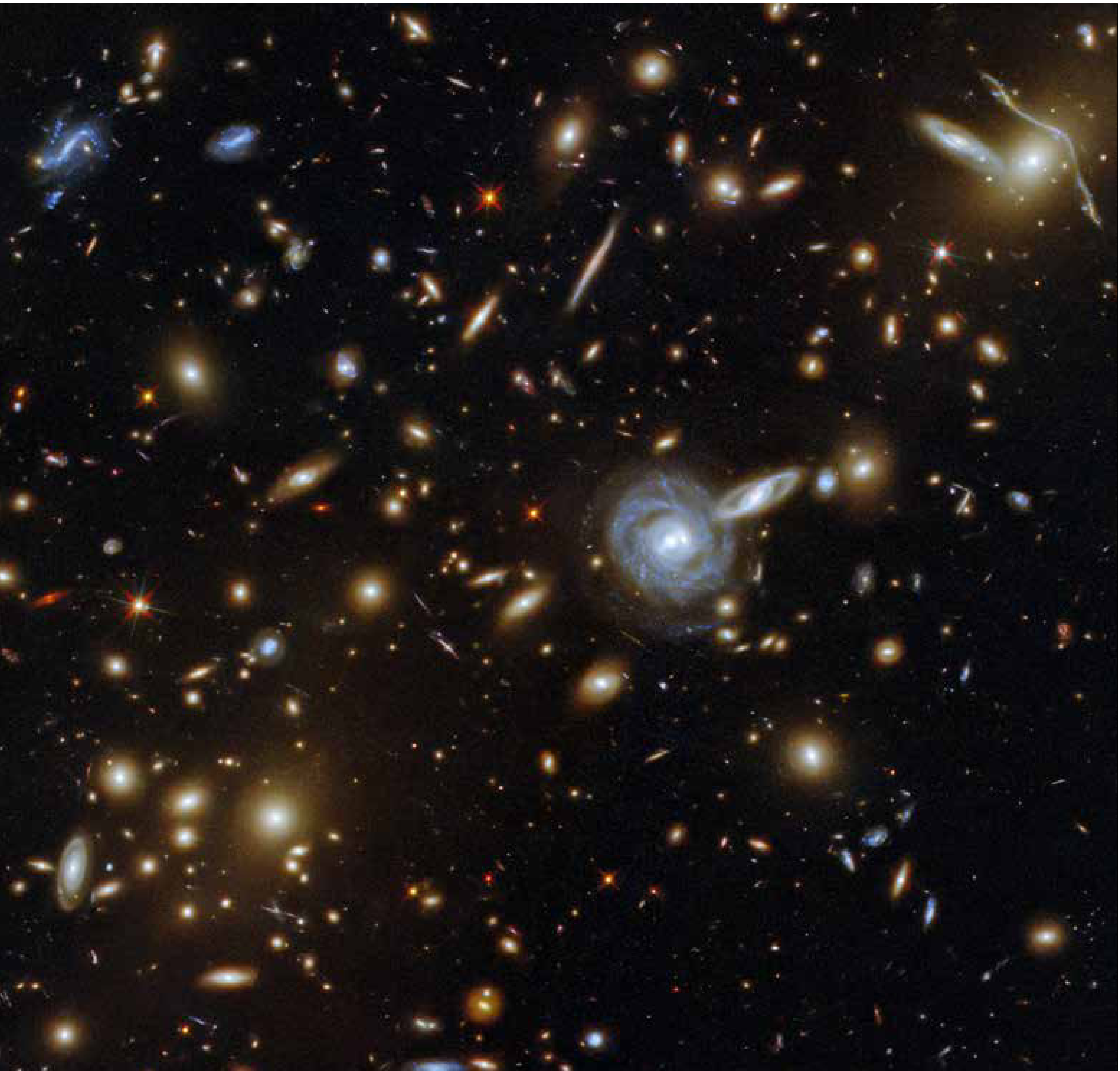
Astronomy Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@astronomy.com.**



TAKE A STEP BACK IN TIME

It can be easy to forget that we see the cosmos not as it is, but as it was. Our view of the Sun is eight minutes old. The next nearest star, Proxima Centauri, appears as it existed 4.2 years ago, and light from the Andromeda Galaxy left 2.5 million years ago. But this view toward galaxy cluster ACO S 295, fittingly located in the southern constellation Horologium the Clock, puts our time machine in overdrive. The cluster's galaxies lie 3.4 billion light-years away, so their light set out shortly after life began on Earth. Yet there's more to this picture. The bright face-on spiral just right of center resides 1.3 billion light-years away, while the elongated arc at upper right is a distorted galaxy some 7.5 billion light-years distant that has been gravitationally lensed by the massive cluster. ESA/HUBBLE & NASA/F. PACAUD/D. COE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ASTROIMAGER BY NIGHT

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AUG 2 SATURN AT OPPOSITION
AUG 19 JUPITER AT OPPOSITION
AUG 22 FULL MOON, SUPERMOON

1. NexYZ DX Smartphone Adapter Kit 2. NexImage Burst Color Imager 3. NexStar Evolution 8 Telescope 4. Nature DX ED 10x42 Binoculars 5. NexYZ 3-Axis Universal Smartphone Adapter

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